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# ENGINEERING AND COST STUDY OF THE FERROALLOY INDUSTRY

Environmental Protection Agency

May 1974

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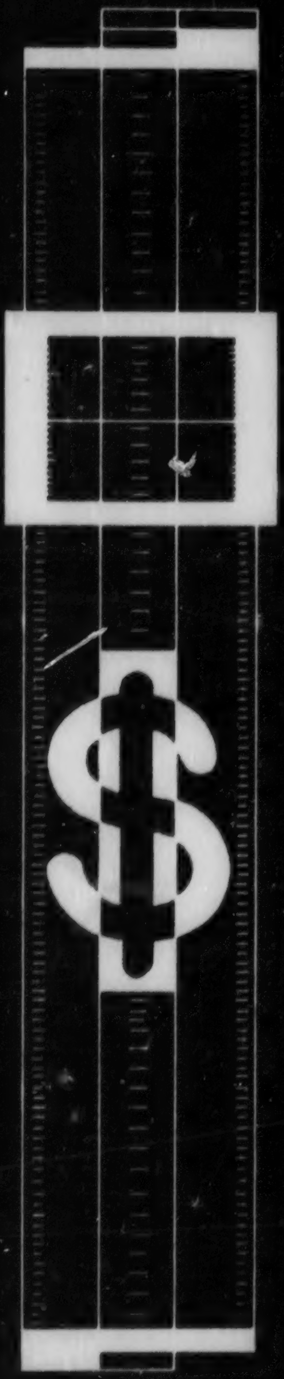

# ENGINEERING AND COST STUDY OF THE FERROALLOY INDUSTRY

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16. ABSTRACT

Report includes a number of studies of several ferroalloy plants and provides information of the following aspects of the industry:

1. Atmospheric emissions from production of ferroalloys and calcium carbide.
2. Methods and equipment used to limit these emissions.
3. Cost and economic impact of air pollution controls.
4. Industry characteristics such as growth rate, raw materials, processes, consumer products, and number and location of producers.

Most of the information herein was gathered from industry questionnaires and EPA source tests.

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James O. Dealy and Arthur M. Killin

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
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# PREFACE

To provide reliable information on the air pollution aspects of the ferroalloy industry, the Office Of Air Quality Planning and Standards of the United States Environmental Protection Agency and the Manufacturing Chemists Association, Inc. (MCA) entered into an agreement on March 2, 1970. On December 21, 1971, the Manufacturing Chemists Association withdrew and the study was completed with the cooperation of the newly formed The Ferroalloy Association (TFA). The cooperative program was established to study atmospheric emissions from selected ferroalloy processes (primarily submerged-arc electric furnaces) and publish information helpful to air pollution control and planning agencies and industry management. Information in the report describes the range of atmospheric emissions during normal operating conditions and the performance of established devices and methods employed to limit and control these emissions.

Direction of this study was vested in a TFA-EPA Steering Committee, presently constituted as follows:

| Representing EPA | Representing TFA |
|---|---|
| Stanley T. Cuffe* | Rolph A. Person* |
| Reid E. Iversen | Fritz E. Brosien |
| John L. McGinnity | Leroy C. Wintersteen |
| John R. O'Connor | Harry U. Gilmer |

Two study team members of the TFA-EPA Steering Committee, Arthur M. Killin, consulting engineer for The Ferroalloy Association, and James O. Dealy, U. S.

---

*Principal representatives.

Environmental Protection Agency, were the principal authors of this report. Also contributing as a study team member was the late Carl V. Spangler of the U.S. Environmental Protection Agency. Kenneth R. Durkee, U.S. Environmental Protection Agency, contributed to this study particularly in providing information on control technology of foreign industry in Japan.

Chapter IX of this report, covering economics of emission control, was authored by Paul Boys, Richard Jenkins and Francis Bunyard of the Economic Analysis Branch, Strategies and Air Standards Division, Office of Air Quality Planning and Standards, Environmental Protection Agency.

# ACKNOWLEDGMENTS

Many companies and individuals in the ferroalloy industry have been helpful in promoting this study. For their contributions, the project sponsors extend their gratitude to: George Fegan, Chromium Mining and Smelting Corporation; A. J. Primosic, Foote Mineral Company; H. U. Gilmer, Woodward Company; Otis D. Jordan, Ohio Ferroalloys Corporation; Dr. Rolph A. Person and Dr. C. R. Allenbach, both of Union Carbide Corporation.

Special thanks are due the following operating companies for their participation in a program of stack sampling specifically for this study:

Airco Alloys and Carbide
Chromium Mining and Smelting Corporation
Foote Mineral Company
Union Carbide Corporation

The sponsors also wish to acknowledge the source testing personnel of the Emission Standards and Engineering Division, Office of Air Quality Planning and Standards, Environmental Protection Agency, and Resources Research, Inc. for their contribution made by stack sampling.

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# AIR POLLUTION CONTROL ENGINEERING AND COST STUDY OF THE FERROALLOY INDUSTRY

## I. INTRODUCTION

In early 1970, a cooperative study on control of atmospheric emissions from the ferroalloy industry was initiated. The study was to be performed jointly by the United States Environmental Protection Agency (then known as the National Air Pollution Control Administration) and the Manufacturing Chemists Association (since replaced by The Ferroalloy Association). The purpose of the study was to prepare guidelines for control agencies and plant management to use in controlling air pollution from the industry and to set priorities for research projects that would result in improved control methods.

The Clean Air Amendments of 1970 were enacted into law after the study was started. Consequently, the report has been supplemented with data to assist industry and government in the implementation of the new law.

The study is culminated in this report, which provides information on the following aspects of the ferroalloy industry:

1. The significance of the industry in the American industrial complex.
2. Industry characteristics such as growth rate, raw materials, processes (other than the manufacture of ferroalloys in a blast furnace), consumer products, and number and location of producers.
3. Atmospheric emissions from production of ferroalloys and calcium carbide.
4. Methods and equipment used to limit these emissions.
5. The cost and economic impact of air pollution control.

6. A brief discussion of water pollution and solid waste disposal problems.

The primary manufacturing process used in the ferroalloy industry is based on the submerged-arc furnace, which is the focus of discussion in this report. The two main sources of data used in this report were (1) questionnaire responses from approximately 80 percent of the United States ferroalloy industry, and (2) measurements of emissions from ferroalloy plant electric furnaces. (The measurements were performed by a contractor of the Environmental Protection Agency and arranged and scheduled with the assistance of The Ferroalloy Association.)

This report has been prepared for air pollution control officials, ferroalloy plant operators and their technical staffs, and others concerned and interested in air pollution emanating from the ferroalloy industry.

Ferroalloys are made from ores in which the metallic constituent has a relatively high affinity for oxygen and for other non-metals, and consequently require substantial quantities of electrical energy in the winning of them from their ores. Ferroalloys include products made by submerged-arc smelting, alumino/silico thermic process, vacuum furnaces, or the electrolytic production of relatively pure metal. The primary products are manganese, chromium,and silicon alloys.

# II. SUMMARY OF STUDY

## A. FERROALLOY PRODUCTION

The United States is the world's largest producer and user of ferroalloys. In 1971 about 2,000,000 tons of ferroalloys were produced by the ferroalloy industry in the United States. In addition, about 400,000 tons of high-carbon ferromanganese were manufactured by the iron and steel industry in blast furnaces.

Ferroalloy consumption in the United States for 1971 was 2.3 million tons exclusive of blast furnace production. Consumption of ferroalloys showed an average annual increase of 2 percent during the 10 years prior to 1972, while production grew at an average rate of 1.5 percent per year. The difference between domestic production and consumption was made up by foreign imports. For the year 1971 imports averaged 380,000 tons or 19 percent of domestic production and had a total value of $116,000,000.

## B. MANUFACTURING PROCESSES

The ferroalloys considered in this study are produced primarily in electric submerged-arc furnaces and to a limited extent in electric open-arc furnaces. Although calcium carbide is not a ferroalloy, it is included in the study because it too is made by the ferroalloy industry in submerged-arc furnaces. Also included are certain ferroalloys produced by the alumino-silico thermic process, vacuum furnace, and electrolytic process. Ferrophosphorus is a ferroalloy produced in submerged-arc furnaces, but because it is made as a byproduct outside of the ferroalloy industry, it is not included in this study.

The submerged-arc furnace consists of a high-temperature refractory-lined crucible with a taphole or arrangement of tapholes at the hearth surface level from which the product is intermittently withdrawn. Over the hearth are vertically suspended carbon electrodes, usually three, arranged in a delta formation. The carbon electrodes, through a system of contact plates, electrode holders for providing vertical movement, and bus bars connected to furnace transformers, convert electrical energy to heat energy within the furnace charge. In the United States there are about 160 submerged-arc ferroalloy furnaces ranging in electrical capacity from 7,500 to 60,000 kilovolt-amperes.

The conventional submerged-arc furnace uses carbon to reduce metallic oxides in the charge and continuously produces large quantities of carbon monoxide along with other gases from volatile matter and moisture in the charge materials. The hot reaction gases rising through the furnace charge carry emissions from the extremely high-temperature interior regions of the furnace and entrain fine particles of charge materials.

## C. TYPICAL EMISSIONS

Total particulate emissions to the atmosphere from electric furnaces in the ferroalloy industry during 1968 were estimated at 150,000 tons. This figure is based on an overall control efficiency of about 40 percent.

Most of the concentrations and mass emission rates shown in this report are based on EPA standard test methods as published in the Federal Register, Volume 36, Number 159, Part II, August 17, 1971, or by that specified by ASME power test code No. 17. Other reported emission rates are based on methods that may not be equivalent to the EPA or ASME methods.

Fume emissions from submerged-arc furnaces are for the most part, directly associated with the evolution of gases (primarily carbon monoxide) from the reduction process. Carbon monoxide emissions from the furnace are substantial and in some cases constitute a larger amount by weight than the metallic product. The amount of fumes and dust from an uncontrolled furnace may vary from about 150 to 2,000 pounds per hour. The amount varies according to the product being made, furnace size, furnace design, charge material preparation, and operating conditions.

Dust and fume concentrations in the untreated furnace gas from covered and open furnaces differ considerably. Concentrations of particulates in the untreated gas from a covered furnace range from 5 to 30 grains per standard cubic foot (gr/scf), whereas particulate concentrations in the untreated gas from an open furnace vary from 0.2 to 2.2 gr/scf. The difference is primarily due to the much lower gas volume from a covered furnace.

Use of an open submerged-arc furnace requires treatment of large volumes of hot gas, up to 500,000 acfm and at temperatures up to 1200°F. These large volumes of gas and fumes formed from the smelting process, consisting of carbon monoxide and evaporated metallic oxides, rises through the charge bed to the surface of the charge. At the surface, the gas is burned with oxygen from the air and very small particles of oxide fumes are formed. The burned reaction gas is immediately diluted with enormous quantities of induced air, making gas cleaning difficult and expensive.

Much smaller volumes of gas (from 3,000 to 7,000 scfm) come from a covered electric furnace. In a covered furnace, unburned carbon monoxide gas is collected under the roof of the cover and withdrawn from the furnace without combustion, resulting in a gas volume which may be as low as 2 percent of that from an open furnace.

The average size (by microscopic count) of fume particles from open furnaces is reported to be less than 0.5 micron. Except for the larger dust particles of feed mix carried from the furnace, the particle fume size is generally below 2 microns and ranges from 0.1 to 1.0 micron with a geometric mean of 0.3 to 0.6 micron, depending upon the ferroalloy produced. In some cases, agglomeration does occur and the effective particle size may be much larger. The bulk density of the dry collected particulates varies (depending upon the product made) from 4 to 30 pounds per cubic foot.

There are two types of covered furnaces. The type used in the United States ferroalloy industry is referred to in this report as a covered furnace with mix seals, but it has also been called a semi-covered or semi-enclosed furnace. This is a furnace with a water-cooled cover where mix materials are charged through openings around the electrodes. The degree of fume escaping the mix seals depends upon the product being made and furnace operating conditions. The other type of covered furnace is referred to in this report as a covered furnace with fixed seals but has also been called a totally enclosed furnace or a sealed furnace. This type of furnace is used to some extent in Europe and Japan. The mix is added through spouts attached to the cover so that the mix columns and control gates provides a gas seal for the furnace. The electrodes are provided with mechanical seals. Visual observations indicate that very little fume escapes from a sealed furnace.

The melting operation in open-arc furnaces, unlike smelting in submerged-arc furnaces, produces less reaction gas. Occasionally large quantities of particulates can be emitted. The open-arc furnace is used to produce an intermediate product for subsequently making low-carbon (LC) and medium-carbon (MC) ferromanganese and LC ferrochrome.

Emissions from the tapping of ferroalloy furnaces are comparatively low. During the tapping interval these emissions are 2 to 4 percent of those from the uncontrolled furnace. Usually the emissions result from the hot gases rising from the molten metal or slag, but in some cases additional gas also issues from the taphole. Most furnaces are tapped periodically; consequently, taphole emissions occur about 10 to 20 percent of the furnace operating time.

The dust emissions from raw material handling and preparation normally are less than 0.25 percent of the material processed. Dust emissions from product sizing and handling are less than 0.05 percent of the material processed.

## D. CONTROL OF PARTICULATE EMISSIONS

Several methods are used to control emissions from electric submerged-arc furnaces. Emissions from open furnaces in the United States industry are controlled by wet scrubbers, cloth filters, and electrostatic precipitators. Emissions from domestic covered furnaces, however, are controlled only by wet scrubbers, primarily because of the high gas temperature and safety hazard of handling carbon monoxide. A few covered furnaces in Japan are reported to use baghouses and electrostatic precipitators. A ceramic filter collector is reported to be operating in Europe on a covered furnace producing calcium carbide.

High-energy wet scrubbers on open furnaces producing silicomanganese, HC ferrochromium, and ferrochrome-silicon have been demonstrated to achieve 96 to 99 percent efficiency when the outlet mass emission rates varied from 11 to 64 pounds per hour depending upon the products and furnace size. Because of the large volumes of gas from an open furnace and high pressure drop across the scrubber, the electrical power requirements of the scrubber system are from 1000 to 3000 horsepower (hp) depending on the product and size of the furnace. In some cases scrubber power needs may be as high as 10 percent of the total power to the furnace.

High-energy venturi scrubber systems used on covered furnaces producing ferromanganese, silicomanganese and 50 percent ferrosilicon was found to remove up to 99.9 percent of the particulates from the collected reaction gases. Because it was unsuitable to make tests at the venturi inlet, calculation of the efficiency was based on uncontrolled emission factors. Depending upon the furnace size and the product, the outlet measured mass emission rate from the venturi scrubber varies from 0.2 to 4.3 pounds per hour and the power requirement for the control system ranges from 200 to 600 hp.

The overall collection efficiencies (excluding tapping emissions) of the two types of covered furnaces differ because of losses from the electrodes on the semi-covered type. The overall collecting efficiency of controls on totally enclosed furnaces has been reported to be better than 99 percent. Covered furnaces with mix seals are operating with overall collecting efficiencies of 75 to 98 percent. Questionnaire data reported particulate losses from mix seals varied from 14 to 462 lb/hr. These losses are dependent upon the product, furnace size and operating conditions. Large totally enclosed furnaces are used in Europe and Japan to produce ferromanganese, silicomanganese and calcium carbide. In Japan, totally enclosed furnaces are used to produce 50-percent ferrosilicon (using iron ore rather than scrap steel), HC ferrochrome (using pretreated feed material), and ferrochrome-silicon (with close metallurgical control). A 12 mw totally enclosed furnace in Japan is producing 75 percent ferrosilicon. The United States ferroalloy industry has not adopted totally enclosed furnaces for the production of these alloys because of safety, flexibility and economics. Covered furnaces with mix seals, used in the United States, produce ferromanganese, 50 percent ferrosilicon, 75 percent ferrosilicon, HC ferrochrome and calcium carbide. The only totally enclosed furnace in the United States produces silicomanganese.

Cloth filters on open ferroalloy furnaces producing silicomanganese, ferrochrome-silicon, and silicon metal have shown collecting efficiencies of about 99 percent. Depending upon the furnace size and the product, the outlet mass emission rate varies from 10 to 17 pounds per hour. The amount of gas flow a cloth filter can handle without blinding when operating on silica fume varies from about 1.5 to 2 cubic feet per minute per square foot of filter area making it necessary to have several thousand bags. The amount of power required for fans on baghouse control systems serving open furnaces in the United States industry varies from 1000 to 4500 hp, depending on the product and size of the furnace. The gas temperature limitation (500°F for treated fiberglass) usually requires provisions for cooling the gas from the furnace. On silica fumes unequal bag life requires frequent bag replacement as the bag life lasts from 18 months to 2 years. The dust collected in the dry state must be handled with care to prevent atmospheric emissions when it is moved to the disposal area; some success has been reported with wetting the dust before disposal.

Electrostatic precipitators have been used in the United States on two large open furnaces producing ferrochromium and ferrochrome-silicon. The overall collecting efficiency (including tapping emissions) on the high-carbon (HC) ferrochrome furnace was more than 98 percent with an average mass emission rate of 21 lb/hr when operated at 33 mw. To enhance the collecting ability of the precipitator, it is necessary to precondition the gases in a preconditioning chamber. Part of the dust is collected in the preconditioning spray chamber, and part is collected in the electrostatic precipitator. Fan horsepower requirements are low, usually about 300 hp for a large furnace.

## E. GUIDELINES FOR EMISSION CONTROL

The present state of knowledge and experience concerning air pollution control equipment limits various types of such devices to specific ferroalloys. A baghouse, scrubber or electrostatic precipitator has not been found to be universally suitable for use on every type of ferroalloy furnace, and on every product, i.e., an electrostatic precipitator can adequately control the emissions from an open furnace producing HC ferrochrome but would not be feasible on an open furnace producing silicon.

A properly designed and operated air pollution control system on an open furnace, which may include an electrostatic precipitator, fabric filter, or scrubber, may be expected to remove 98 percent or greater of the total particulate emissions from the furnace. Four out of five EPA tests show mass emission rates below 1 pound per mw-hr can be achieved for open furnaces. Although the fifth test showed it was slightly over the 1 pound per mw-hr emission rate, the control device has some compensation advantages in energy conservation. These rates vary depending upon the product and control device used.

Wet scrubbers are generally used to clean the collected gases from covered furnaces. The particulate concentation in the clean gas ranges from 0.01 to 0.07 gr/scf, depending upon the product. The scrubbers are expected to have an efficiency of over 99 percent. EPA tests show mass emission rates from these scrubbers are less than 0.10 lb/mw-hr.

The clean gas from a covered furnace is either flared without visible emissions or used as fuel. In some cases covered furnaces with mix seals require additional control equipment to control the fugitive fumes escaping from the mix seals. On the other hand, covered furnaces with fixed seals do not require additional control equipment because the fugitive fume losses from the electrode seals are held to a minimum and can be expected to meet visual criteria.

Tapping fumes from a covered furnace cannot be controlled by the primary control system serving the furnace. They require a separate control system. The air pollution control system serving an open furnace can be designed to include the control of emissions from the tapping station.

Higher than normal gaseous emissions from ferroalloy furnaces will generally occur during periods of startup and prior to shutdown, periods of poor tapping and excessive blowing caused by metallurgical problems, and periods of mechanical failure of furnace equipment and the emission control device.

Based on EPA test data, the mass emission rates from control systems serving open furnaces were less than 0.50 lb/mw-hr for silicomanganese and ferrochrome silicon production; less than 0.70 lb/mw-hr for HC ferrochrome production; and less than 1.0 lb/mw-hr for silicon production.

## F. RESEARCH AREAS

Research and development may find new and better uses for totally enclosed furnaces (covered furnaces with fixed seals) in the United States. A worldwide evaluation could be made of totally enclosed furnace designs, operating techniques, and manufacturing limitations and capabilities. The goal of such an evaluation would be to determine the extent to which these furnaces can be used in manufacturing various alloys other than those for which they are already used.

Several other means by which research and development may help reduce particulate emissions or lower the cost of production are:

(1) Examine raw materials and material pretreatment that could result in a lower quantity of particulate emissions;

(2) Determine to what extent collected particulates may be recycled;

(3) Search for new uses of collected particulates that may be sold to other industries;

(4) Investigate techniques of agglomeration by sonic, electrostatic, or other means;

(5) Investigate other uses for waste heat recovery of furnace reaction gas;

(6) Determine the extent and method of control of ladle fumes.

## G. ECONOMIC IMPACT OF EMISSION CONTROL

Estimated industry profits ranged from 0 to 5 percent of sales in recent years. Prices are anticipated to remain weak in the foreseeable future due to overcapacity and strong competition from foreign manufacturers.

In 1970 about 50 percent of the existing furnace capacity operating in the United States was equipped with particulate emission control systems with efficiencies ranging from about 75 to 99 percent. The estimated cost of installing new control equipment on the remaining uncontrolled furnaces is expected to be over $120 million.

# III. FERROALLOYS

## A. HISTORICAL BACKGROUND

The beneficial influence of metals on the progress of modern civilization is widely evident; no other material has so many economical applications. Versatility, the keystone of success for metals, is dependent in large measure on the alloying materials that provide the special properties needed for specific applications.

More than 50 different alloys and metals, in hundreds of various compositions and sizes, are produced by the ferroalloy industry for use in the manufacture of steel, iron, and nonferrous metals.

> The term "ferroalloys" is defined by Webster's New International Dictionary of the English Language (1961) as "a crude alloy of iron with some other metal, used for deoxidizing molten steel and making alloy steels." In practice, however, the term is used loosely to include alloys or compounds containing little or no iron, and even relatively pure metals, employed to introduce additive or alloying elements in the production of steel. "Addition agent" is perhaps a more correct terminology . . . although not as freely employed. In using the term "ferroalloys" in the treatment of its statistics, the Bureau of Mines goes beyond the strict definition, following the sense of the general Webster definition of the prefix "ferro-" as denoting the "presence of, or connection with, iron."[1]

Ferroalloys include products made by submerged-arc smelting, the electric furnace alumino/silico thermic process, vacuum furnaces, and the electrolytic production of some relatively pure metals. These do not include aluminum, magnesium, iron and steel, cadmium, copper, nickel, lead, zinc, products of the chloralkali industry or products such as beryllium and uranium made by the metallurgical extraction process. Table III-1 shows a list of

Table III-1. COMPOSITION OF FERROALLOYS[a]

| Ferroalloy | Chemicals | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mn | Fe | C | Si | S | Al | Cr | Ca | Mo | V | Ti | W | Zr | Cb |
| Ferromanganese | 78 | | | | | | | | | | | | | |
| Spiegeleisen | 16 to 19<br>19 to 21<br>21 to 23 | | | | | | | | | | | | | |
| Ferromanganese silicon | 63 to 66 | | | 20 to 22 | | | | | | | | | | |
| Medium-carbon (MC) ferromanganese | 80 to 85 | | 1.25 to 1.50 | 1.50 max. | | | | | | | | | | |
| Low-carbon (LC) ferromanganese | | | 0.10 max.<br>0.30<br>0.75 | | | | | | | | | | | |
| Electrolytic manganese | 99.9 | | | | | | | | | | | | | |
| Standard LC ferrochrome | | | 0.05<br>0.020 | | | | 67 to 73<br>67 to 73 | | | | | | | |
| Simplex ferrochrome | | | 0.010<br>0.020 | | | | 68 to 72<br>68 to 72 | | | | | | | |
| Ferrochrome:<br>Charge Cr<br>9% C Cr<br>HS Cr 50<br>Chromsol Fe Cr<br>Blocking C Reg.<br>High-carbon (HC) FeCr | | | 9<br>5.5 to 6<br>5.5 to 6<br>5<br>4.5 to 6 | | | | 64 to 67<br>52 to 55<br>65 to 68<br>65 min.<br>65 min.<br>60 to 67<br>67 to 70 | | | | | | | |
| Ferrochrome-silicon:<br>36/40<br>40/43<br>LC grade | | | | 40<br>43 | | | 36<br>40 | | | | | | | |
| Silicon metal | | 0.35<br>0.50<br>1.00<br>1.50 | | | | | | | | | | | | |
| Ferromolybdenum | | | | | | | | | 60 to 60 | | | | | |
| Vanadium metal | | | | | | | | | | 90 | | | | |
| Chromium metal<br>9% C metal | | | 9 | | | | 99.8 | | | | | | | |
| 50% Ferrosilicon | | | | 50 | | 0.40 max.<br>0.10 | | | | | | | | |
| 65% Ferrosilicon<br>High pority | | | | 65<br>65 | | | | | | | | | | |
| 75% Ferrosilicon<br>0.5% Ca<br>Low Al | | | | 75<br>75<br>75 | | | | 0.5 | | | | | | |
| 85% Ferrosilicon<br>0.5% Ca<br>Low Al<br>0.5 to 1.5% Ca | | | | 85<br>85<br>85<br>85 | | | | 0.5<br>0.5 to 1.5 | | | | | | |
| SMZ alloy | 5 to 7 | | | 60 to 65 | | | | | | | | | 5 to 7 | |
| Magnesium ferrosilicon<br>5% Mg<br>9% Mg | | | | 50<br>50 | | | | | | | | | | |
| Silvery pig iron | | | | 14<br>16<br>22 | | | | | | | | | | |
| Ferrotitanium | | | 0.10 max. | | | | | | | | 70 | | | |
| Ferrocolumbium | | 35 | | | | | | | | | | | | 55 to 60 |
| Alsifer | | | | 40 | | 20 | | | | | | | | |
| Ferrotungsten<br>High pority<br>Low moly<br>High moly | | | | | | | | | | | | 77 to 83<br>76 to 84<br>76 to 84 | | |
| Ferrovanadium | | | | | | | | | | 52 to 57<br>70 to 75 | | | | |
| Silico manganese<br>3% C grade<br>2% C grade<br>1.5% C grade<br>Low C<br>High Mn | 65 to 68<br>65 to 68<br>65 to 68<br>65 to 68<br>73 | | 3<br>2<br>1.5 | 12 to 14.5<br>15 to 17.5<br>18 to 20 | | | | | | | | | | |
| Calcium silicon | | 1.50 to 3.0 | | 60 to 65 | | | | 30 to 33 | | | | | | |

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[a] American Metal Market, February 3, 1972.

ferroalloy products with general specifications. The industry also produces materials used in the manufacture of chemicals, welding rod coatings, and catalysts.

The demand for ferroalloys is governed to a large extent by the requirements of the iron and steel industry for steels of greater strength and corrosion resistance, qualities that are affected both by internal composition and external coatings. Basic to both higher strength and greater corrosion resistance in steel is the deliberate adjustment of the iron and carbon content of the steel and the addition of other metal. These other metals are precisely classified as ferro additives, but are more commonly known as ferroalloys--the products of the ferroalloy industry.

Before 1890, ferroalloys were made in the blast furnace and to a limited extent in the open-hearth furnace. These ferroalloys were high-carbon (HC) ferromanganese, low-percentage-manganese alloys such as spiegeleisen and silicon-spiegel, and 15-percent ferrosilicon. The blast furnace method is still used to make about 70 percent of the HC ferromanganese today. Temperatures are not high enough in the blast furnace or open-hearth furnace for the reduction of most of the other refractory oxides of the alloying metals; also, low-carbon (LC) alloys cannot be produced in these furnaces.

The introduction of the electric submerged-arc furnace resulted from the invention of the electric dynamo in 1867 and from the experimental work on the electric-arc furnace by Sir W. Siemens in 1878. The calcium carbide industry began in 1892 with the use of the electric submerged-arc furnace. The ferroalloy industry actually began about 6 years later when the industry found it had an overcapacity of calcium carbide production equipment and was forced to find other products that could be made in their furnaces. About this time, the technique was first perfected for making HC ferrochromium and ferrosilicon alloys in the electric furnace. In 1898, the Spanish American War created a relatively large demand for ferrochrome to produce stronger steel for use in armor plate and projectiles. Also, ferrosilicon was in demand as a deoxidizer in producing steel of a higher grade. Further refinements in the furnace design allowed the industry to produce newer and higher-grade ferroalloys.

The discovery and development of the principal alloying elements of manganese, silicon, chromium, calcium, vanadium, tungsten, molybdenum, zirconium, columbium, titanium, and boron are of historical interest. All of these metals were first made during a relatively short period of about 35 years beginning in 1774; however, the full metallurgical benefits from the use of these alloying metals were not known until the twentieth century.

## 1. Manganese and Manganese Alloys

Manganese is used in the production of every grade of steel. The function of manganese in steel is threefold:

(1) It acts as a deoxidizer and cleanser of the molten steel.

(2) It combines with sulfur, thereby greatly improving the hot-working properties of the steel.

(3) It acts as an alloying element to improve the strength, toughness, and response to heat treatment of a wide variety of structural and engineering steels.

Metallic manganese was first produced by the Swedish mineralogist, Johan Gottlieb Gahn, in 1774. There were no important developments concerning the use of manganese in the manufacture of steel until about 1839, when manganese carbide was used in the manufacture of crucible steel. In 1856 Robert Musket used manganese in the form of spiegeleisen to make the Bessemer process a success. About the same time, William Siemens patented the use of ferromanganese as an addition to molten steel to counteract the adverse effects of sulfur. In 1888 Robert Hadfield announced the discovery of the high-manganese steel generally known as Hadfield manganese steel.

Because standard ferromanganese is relatively high in carbon, it has some disadvantages for use in steels that must have a high manganese content and a low carbon content. The advent of commercial electric furnaces made it possible to control carbon content in ferromanganese, however, and ferromanganese with a low carbon content was soon manufactured.

### 2. Silicon and Silicon Alloys

Silicon is used in the iron, steel, and nonferrous metal industries. Various grades of ferrosilicon are used by the iron and steel industries as deoxidizers and alloying elements. Silicon metal is used in the aluminum industry as an alloying agent and in the chemical industry for producing silicones. Silicon is used in manufacturing steel sheets for electrical apparatus such as transformers, motors, generators, and electromagnets. The silicon content in the iron is important because it decreases the electrical energy loss from magnetization.

In the year 1810 the Swedish scientist Berzelius produced the world's first ferrosilicon. Fourteen years later he succeeded in producing the first silicon metal. Ferrosilicon with as much as 22 percent silicon was produced in 1870 by Volten. Since then, the advantages of ferrosilicon in manufacturing steel have become recognized.

### 3. Chromium and Chromium Alloys

Chromium is one of the most important alloying metals in modern iron and steel metallurgy. The well-known "stainless" and "heat resistant" steels resist corrosion and oxidation at high temperatures because substantial percentages of chromium are present. Improved mechanical properties and increased susceptibility to heat treatment are imparted to engineering steels by adding 1.0 to 3.5 percent chromium.

Chromium was discovered in 1797 by the French chemist Vauguelin. The first chromium alloy was made in 1821 by Berthier, who was the first to produce chromium steels and to recognize the improved properties that chromium imparted to steel.

### 4. Other Metals

Other alloying metals such as vanadium, columbium, and molybdenum add important beneficial properties to iron and steel, even though small percentages may be used.

## B. CURRENT USES AND PRODUCTION

The joint effort of the steel and ferroalloy industry to manufacture improved products for today's requirements has resulted in exceedingly high-strength steels.[1] These steels provide yield and tensile strengths (in excess of 100,000 pounds per square inch) that are about twice those of high-strength, low-alloy steels, and three times as great as those of carbon steels. Improvements of similar magnitude have been accomplished in manufacturing corrosion-resistant steels and high-temperature alloys. The improvements apply equally for the nonferrous metals, such as aluminum, copper, magnesium, and nickel.

The principal ferro additives used as deoxidizers and cleansers of molten steel are manganese and silicon, and to a lesser extent calcium, titanium, and zirconium. Those used for imparting special properties to steel and nonferrous metals or to the formation of alloy steels are manganese, silicon, chromium, columbium, vanadium, tungsten, molybdenum, zirconium, and other minor tonnage materials.

The United States ferroalloy industry is still the largest in the world but foreign production has increased at a rapid rate particularly in Japan, South Africa, and Norway (Tables III-2 and III-3). During the 1950's and 1960's, the high level of steel production and U. S. government purchases for stockpiling resulted in an increased demand for ferroalloys. This increased demand, however, gave foreign ferroalloy producers greater incentive to compete for the United States market.

From 1950 to 1965, the United States increased production of specialty ferroalloys, excluding ferromanganese and ferrosilicon, from 196,856 to 1,020,000 tons per year.[2]

Table III-2. WORLD STEEL PRODUCTION VS FERROALLOY TURNOVER[2]

| Country | Steel production, net tons[a] | Ferroalloy turnover, net tons[a] |
|---|---|---|
| USA | 131,000,000 | 2,820,000 |
| USSR | 100,000,000 | 2,120,000 |
| Japan | 45,100,000 | 860,000[b] |
| Germany (W) | 40,600,000 | 740,000 |
| United Kingdom | 30,000,000 | 471,000 |
| France | 21,600,000 | 658,000[c] |
| Belgium-Luxembourg | 15,200,000 | 180,000[d] |
| Italy | 13,900,000 | 300,000 |
| Poland | 10,000,000 | 120,000[d] |
| Canada | 9,800,000 | 200,000 |
| Czechoslovakia | 9,500,000 | 90,000 |
| India | 6,900,000 | 150,000 |
| Australia | 5,500,000 | 100,000 |
| Sweden | 5,200,000 | 185,000 |
| Germany (E) | 4,400,000 | 23,000 |
| Spain | 3,800,000 | 71,500 |
| Austria | 3,600,000 | 50,000[e] |
| Netherlands | 3,400,000 | 68,000 |
| Brazil | 3,300,000 | 35,000[f] |
| S. Africa | 3,000,000 | 365,000 |
| Yugoslavia | 1,900,000 | 54,000 |
| Norway | 800,000 | 440,000 |
| Turkey | 700,000 | 10,500[g] |
| Bulgaria | 600,000 | 8,000[d] |
| Others | 200,000 | 3,000[d] |
| Total | 501,000,000 | 10,020,000 |

[a] 1965 figures (latest available information) except where otherwise indicated.

[b] 1964 figure, including estimated imports of 30,000 tons.

[c] 1965 figures, includes 285,000 export tons.

[d] Estimate.

[e] Nearly all Austrian ferroalloys are imported.

[f] Statistics available from ILAFA 1962 date, when Brazil's steel production was 2,800,000.

[g] Includes 5,000 tons of imports.

### Table III-3. FERROALLOY PRODUCTION IN THE UNITED STATES[3]
(short tons)

| Ferroalloy | 1967 | 1968 | 1969 | 1970 | 1971 |
|---|---|---|---|---|---|
| Ferromanganese:[a] |  |  |  | 835,463[f] | 759,896[f] |
| Blast furnace | 651,987 | 562,541 | 510,925 |  |  |
| Electric furnace[b] | 295,223 | 317,421 | 341,094 |  |  |
| Silicomanganese | 253,134 | 284,499 | 222,877 | 193,219 | 164,682 |
| Ferrosilicon | 575,689 | 665,383 | 715,172 | 709,287 | 687,166 |
| Silvery iron: | 255,064[g] |  |  | 196,369 | 171,788 |
| Blast furnace |  | 28,414 | 39,275 |  |  |
| Electric furnace |  | 166,181 | 164,752 |  |  |
| Chromium alloys: |  |  |  |  |  |
| Ferrochromium[c] | 309,786 | 281,697 | 296,305 | 309,613 | 248,165 |
| Other chromium alloys[d] | 134,039 | 107,875 | 122,733 | 96,163 | 107,493 |
| Ferrotitanium | 5,526 | 4,130 | 4,441 | 3,360 | 3,363 |
| Other[e] | 101,802 | 86,197 | 80,347 | 87,607 | 87,159 |
| Totals | 2,582,250 | 2,504,338 | 2,497,921 | 2,431,081 | 2,229,702 |

[a] Includes briquets.

[b] Includes fused-salt electrolytic.

[c] Includes low- and high-carbon ferrochromium and chromium briquets.

[d] Includes ferrochrome-silicon, exothermic chromium additives, and other chromium alloys.

[e] Includes ferrocolumbium, alsifer, ferroboron, ferronickel, ferromolybdenum, ferrotungsten, ferrovanadium, Simanal, speigeleisen, zirconium-ferrosilicon, ferrosilicon-zirconium, and other miscellaneous ferroalloys.

[f] Blast furnace and electric furnace productions of ferromanganese combined.

[g] Blast furnace and electric furnace productions of silvery iron combined.

Ferroalloy imports also increased for every product during the years from 1960 through 1972. United States imports of selected ferroalloys for domestic consumption during this period are shown in Table III-4, along with the amount of United States consumption and the percentage of imported ferroalloys. Table III-5 shows the amount of ferroalloys imported for the United States Government stockpile.

## C. FUTURE TRENDS

The continuing increase in the use of ferroalloys as additives per ton of steel is the result of the demand for more service per pound of steel used. As various materials compete in the market place, steels will need to be tougher and longer lasting. To achieve these qualities, steelmakers will need to continue improving steel production technology and the capabilities of steel products. This means new uses and greater amounts of ferro additives.

Table III-6 shows the trend of ferroalloys being used by the steel industry. Ferroalloys used in the production of stainless steels are anticipated to show a modest increase in the United States. Table III-7 shows the production of stainless steel in the United States and the free world. The table shows that United States production of stainless steel changed very little from 1965 to 1970. Stainless steel production in Europe and Japan, on the other hand, increased significantly during this time.

Electric furnaces are now 10 times larger than those of 20 years ago. Units of 40,000 kilovolt-amperes (kv-a) and higher are becoming

## Table III-4. IMPORTS OF SELECTED FERROALLOYS (EXCLUDING IMPORTS TO GOVERNMENT STOCKPILE) AS RELATED TO DOMESTIC FERROALLOY CONSUMPTION[4]

(net tons alloy except where otherwise indicated)

| Ferroalloy | Year | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1960 | 1962 | 1964 | 1966 | 1968 | 1970 | 1972 |
| HC ferromanganese | | | | | | | |
| Total consumption | 733,536 | 739,988 | 925,213 | 942,270 | 907,228 | 852,021 | 800,640 |
| Imports for consumption | 54,997 | 104,663 | 120,452 | 216,146 | 182,286 | 263,395 | 290,274 |
| Imports as % of total | 7.5 | 14.1 | 13.0 | 22.9 | 20.1 | 30.9 | 33.3 |
| Electric furnace production imports as % of total | 27.6 | 40.8 | 37.3 | 74.4 | 48.3 | 55.9 | 66.0 |
| Silicomanganese | | | | | | | |
| Total consumption | 98,634 | 122,342 | 175,224 | 174,157 | 164,632 | 135,806 | 120,300 |
| Imports for consumption | 15,455 | 26,389 | 10,841 | 35,771 | 25,412 | 14,447 | 38,540 |
| Imports as % of total | 15.7 | 21.6 | 6.2 | 20.5 | 15.4 | 10.6 | 32.0 |
| MC and LC ferromanganese | | | | | | | |
| Total consumption | 66,894 | 65,453 | 82,410 | 106,159 | 109,331 | 127,153 | 140,720 |
| Imports for consumption | 10,912 | 13,866 | 11,529 | 27,817 | 20,926 | 23,276 | 58,318 |
| Imports as % of total | 16.3 | 21.2 | 14.0 | 26.2 | 19.1 | 18.3 | 41.4 |
| Manganese metal | | | | | | | |
| Total consumption | 15,733 | 14,851 | 25,734 | 24,838 | 25,703 | 17,089 | 30,000 |
| Imports for consumption | 243 | 1,504 | 819 | 2,020 | 3,183 | 1,277 | 4,119 |
| Imports as % of total | 1.5 | 10.1 | 3.2 | 8.1 | 12.4 | 7.5 | 13.7 |
| HC ferrochrome | | | | | | | |
| Total consumption | 82,000 | 95,128 | 125,818 | 142,853 | 135,830 | 116,371 | 179,170 |
| Imports for consumption | 1,891 | 12,442 | 7,470 | 23,883 | 8,259 | 12,333 | 73,073 |
| Imports as a % of total | 2.3 | 13.1 | 5.9 | 16.7 | 6.1 | 10.6 | 36.0 |

### Table III-4. IMPORTS OF SELECTED FERROALLOYS (EXCLUDING IMPORTS TO GOVERNMENT STOCKPILE) AS RELATED TO DOMESTIC FERROALLOY CONSUMPTION
(net tons alloy except where otherwise indicated)

| Ferroalloy | Year |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
|  | 1960 | 1962 | 1964 | 1966 | 1968 | 1970 | 1972 |
| LC ferrochrome |  |  |  |  |  |  |  |
| Total consumption | 92,026 | 96,579 | 148,800 | 171,074 | 152,215 | 149,548 | 118,944 |
| Imports for consumption | 5,099 | 24,084 | 18,652 | 74,111 | 51,557 | 27,851 | 68,192 |
| Imports as % of total | 5.5 | 24.9 | 12.5 | 43.3 | 33.9 | 18.6 | 57.4 |
| Chromium metal |  |  |  |  |  |  |  |
| Total consumption | N.A.[a] | N.A. | N.A. | N.A. | N.A. | N.A. | 3,470 |
| Imports for consumption | 216 | 648 | 733 | 2,487 | 1,366 | 1,892 | 1,893 |
| Imports as % of total | - | - | - | - | - | - | 54.6 |
| Ferrosilicon 60 to 80% |  |  |  |  |  |  |  |
| Total consumption | 71,588 | 74,358 | 86,561 | 98,561 | 92,626 | 97,264 | 127,467 |
| Imports for consumption | 3,381 | 71 | 1,670 | 12,195 | 7,224 | 8,884 | 24,916 |
| Imports as % of total | 4.7 | 0.1 | 1.9 | 12.4 | 7.8 | 9.1 | 19.5 |

[a] N.A. = Not Available

Table III-5. IMPORTS OF SELECTED FERROALLOYS FOR U.S. GOVERNMENT STOCKPILE[4]
(net tons alloy)

| Ferroalloy | Year | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1960 | 1962 | 1964 | 1966 | 1968 | 1970 | 1972 |
| HC ferromanganese | 54,313 | 7,085 | 68,689 | 8,099 | -0- | -0- | -0- |
| MC ferromanganese | -0- | -0- | 11,956 | -0- | -0- | -0- | -0- |
| Manganese metal | -0- | -0- | 59 | -0- | -0- | -0- | -0- |
| HC ferrochrome | 31,634 | -0- | -0- | -0- | -0- | -0- | -0- |
| LC ferrochrome | 10,763 | -0- | -0- | -0- | -0- | -0- | -0- |
| Chromium metal | 692 | -0- | -0- | -0- | -0- | -0- | -0- |

Table III-6. POUNDS OF ELEMENT CONSUMED PER TON OF STEEL PRODUCTION[6]

| Element | Year<br>1950 | <br>1970 | <br>1980 (projected) |
|---|---|---|---|
| Manganese | 14.5 | 14.5 | 14.5 |
| Silicon | 5.8 | 6.0 | 6.1 |
| Chromium | 1.7 | 3.6 | 3.5 |

Table III-7. PRODUCTION OF STAINLESS STEEL IN FREE WORLD[7]
(net tons)

| Year | U.S.A. | West Europe | Japan | Total |
|---|---|---|---|---|
| 1965 | 1,490,000 | 1,520,000 | 635,000 | 3,645,000 |
| 1966 | 1,645,000 | 1,660,000 | 730,000 | 4,035,000 |
| 1967 | 1,450,000 | 1,800,000 | 1,040,000 | 4,290,000 |
| 1968 | 1,430,000 | 1,990,000 | 1,150,000 | 4,570,000 |
| 1969 | 1,565,000 | 2,050,000 | 1,490,000 | 5,105,000 |
| EST.1970 | 1,330,000 | 2,080,000 | 1,595,000 | 5,005,000 |
| EST.1975 | 1,595,000 | 2,810,000 | 2,200,000 | 6,605,000 |
| EST.1980 | 1,790,000 | 3,440,000 | 2,750,000 | 7,980,000 |

common. A number of furnaces of about 60,000 kv-a are operating and new units of 72,000 kv-a are being planned. It will be increasingly difficult for ferroalloy plants that are not installing larger furnaces and material handling facilities to maintain competitive positions.

The demand for ferroalloys should continue to grow at a faster rate than its major customer, the steel industry, because the growth rate of materials requiring alloy additives is two to three times that of plain-carbon steels. Pressure by steel's users for higher-performance steels should accelerate this demand for alloys.

The growth of steel production in the United States has been projected by Battelle Memorial Institute for the United States Government in a technological report (see Table III-8).[8]

Table III-8. PRODUCTION OF RAW STEEL IN THE UNITED STATES BY TYPE OF FURNACE AND PROJECTIONS OF PRODUCTION TO 1980[8]
(1000 net tons)

| Year | Type of furnace | | | | Total |
|---|---|---|---|---|---|
| | Open hearth | Bessemer | Basic oxygen | Electric | |
| 1960 | 86,368 | 1,189 | 3,346 | 8,379 | 99,282 |
| 1967 | 70,690 | a | 41,434 | 15,089 | 127,213 |
| 1975 | 44,000 | - | 80,000 | 33,000 | 157,000 |
| 1980 | 36,000 | - | 99,000 | 45,000 | 180,000 |

[a] Included with open-hearth production; 278,000 tons of Bessemer steel were reported in 1966.

# IV. FERROALLOY PLANTS IN THE UNITED STATES

Table IV-1, entitled "Types, Sizes, and Locations of Ferroalloy Producing Plants in the United States," tabulates the 44 known producing plants in the United States through 1971. The listing is given on the basis of ownership and the geographic locations of the plants. Also listed are known products produced at each plant, general run of products made, type of furnaces, and numbers of those producing ferroalloys and those producing calcium carbide. This tabulation is representative of 1971 status and it should be recognized that the companies may frequently change their product lines, take furnaces out of service, and start up idle capacity according to product demand or operating requirements. The list does not reflect furnaces under construction or those out of service. A total of 145 furnaces are listed as producing ferroalloys, and 13 produce calcium carbide.

A map of the United States, Figure IV-1, shows the number and approximate geographical location of ferroalloy plants in each state. Table IV-2 shows a list of ferroalloy plants and electric furnaces by states. Ohio leads with eight plants that have a total of 58 electric furnaces. West Virginia has the second highest number of furnaces, 25 in three plants.

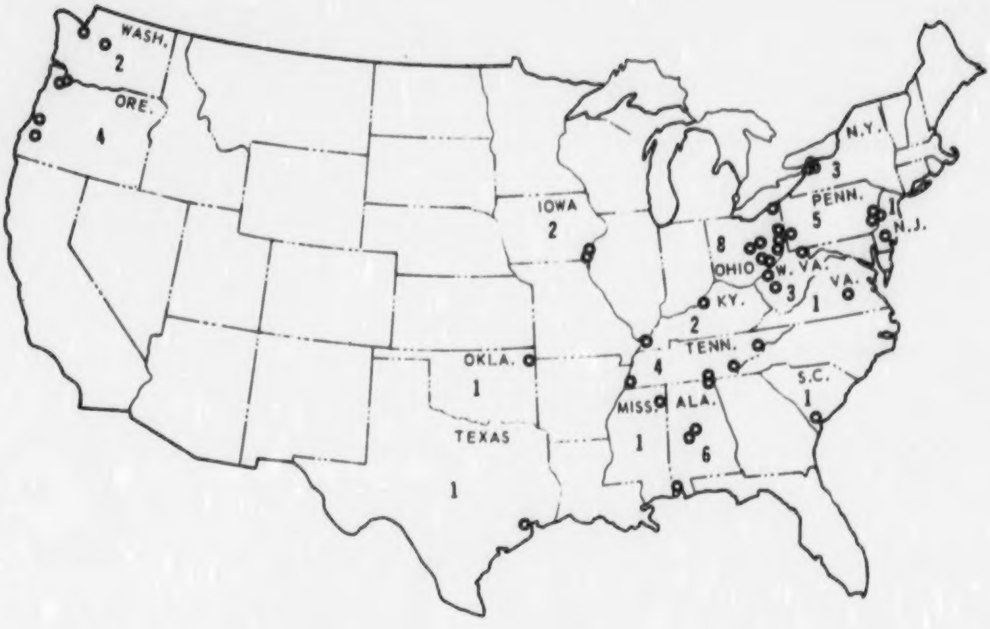
Table IV-1. TYPES, SIZES, AND LOCATIONS OF FERROALLOY PRODUCING PLANTS IN THE UNITED STATES, August 1971[3]

|  | Producers | Plant size[a] | Locations | Products | Type of furnace | No furnaces |  |
|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  | Alloy | Carbide |
| 1 | Air Reduction Co., Inc. | L | Calvert City, Ky. | FeCr, FeMn, FeSi, FeCrSi, $CaC_2$ | Electric | 11 | 3 |
| 2 | Airco Alloys Div. | M | Charleston, S. C. |  | Electric | 2 |  |
| 3 |  | M | Niagara Falls, N. Y. |  | Electric | 1 |  |
| 4 |  | S | Theodore, Ala. |  | Electric | 1 |  |
| 5 |  | M | Louisville, Ky. | $CaC_2$ | Electric |  | 1 |
| 6 | American Potash Co. | S | Aberdeen, Miss. | Mn | Electrolytic |  |  |
| 7 | Chromium Mining and Smelting Co. | M | Woodstock, Tenn. | FeMn, SiMn, FeSi, FeCr, FeCrSi | Electric | 5 |  |
| 8 | Climax Molybdenum Co. | S | Langeloth, Pa. | FeMo | Aluminothermic |  |  |
| 9 | Foote Mineral Co. | S | Cambridge, Ohio | FeB, FeCb, FeTi, FeV, other | Electric | 2 |  |
| 10 |  | L | Graham, W. Va. | FeCr, FeCrSi, FeSi, other | Electric | 9 |  |
| 11 |  | M | Keokuk, Iowa | FeSi, Silvery Iron | Electric |  |  |
| 12 |  | S | N. Johnsonville, Tenn. | Mn | Electrolytic | 5 |  |
| 13 |  | M | Steubenville, Ohio | FeCr, FeCrSi | Electric | 6 |  |
| 14 |  | M | Wenatchee, Wash. | FeSi, Si | Electric | 4 |  |
| 15 | Hanna Nickel Smelting Co. | S | Riddle, Oreg. | FeSi | Electric | 4 |  |
| 16 | Interlake Steel Corp. | L | Beverly, Ohio | FeCr, FeSi, SiMn | Electric | 7 |  |
| 17 | Kawecki Berylco Industries | S | Springfield, Oreg. | Si | Electric | 2 |  |
| 18 | Kawecki Chemical Co. | S | Easton, Pa. | FeCb | Aluminothermic |  |  |
| 19 | Luckenby | S | Selma, Ala. | FeSi | Electric | 1 |  |
| 20 | Manganese Chemicals Co., Diamond Shamrock | S | Kingwood, W. Va. | FeMn | Electric |  |  |
| 21 | Midwest Carbide Co. | S | Keocuk, Iowa | $CaC_2$ | Electric |  | 1 |
| 22 |  | S | Muskogee, Okla. | $CaC_2$ | Electric |  | 1 |
| 23 | Molybdenum Corporation of America | S | Washington, Pa. | FeMo | Electric & aluminothermic |  |  |
| 24 | National Lead Co. | S | Niagara Falls, N. Y. | FeCbTi, FeTi, other | Electric | 3 |  |
| 25 | New Jersey Zinc Co. | S | Palmerton, Pa. | Spiegeleisen | Electric | 1 |  |
| 26 | Ohio Ferro Alloy Corp. | M | Brilliant, Ohio | FeCr, FeSi, Si, FeCrSi | Electric | 4 |  |
| 27 |  | L | Philo, Ohio | FeB, FeMn, FeSi, SiMn, Si | Electric | 10 |  |
| 28 |  | M | Powhaton, Ohio | FeSi, Si | Electric | 4 |  |
| 29 |  | S | Tacoma, Wash. | FeCr, FeSi | Electric | 2 |  |
| 30 | Pacific Carbide Co. | S | Portland, Oreg. | $CaC_2$ | Electric |  | 1 |
| 31 | Reynolds Metals Co. | S | Lister Hill, Ala. | Si | Electric | 1 |  |
| 32 | Reading Alloys | S | Robesonia, Pa. | FeB, FeCb, FeV, NiCb, FeMo | Aluminothermic |  |  |
| 33 | Sandgate Corp. | S | Houston, Tex. | FeMn, SiMn | Electric | 3 |  |
| 34 | Shieldalloy Corp. | S | Newfield, N. J. | FeV, FeTi, FeB, FeMo, FeCb, FeCbTa | Aluminothermic |  |  |
| 35 | Tennessee Alloys Corp. | S | Bridgeport, Ala. | FeSi | Electric | 3 |  |
| 36 | Tennessee Metallurgical Co. | S | Kimball, Tenn. | FeSi | Electric | 2 |  |
| 37 | Union Carbide Corp. | L | Alloy, W. Va. | FeB, FeCr, FeCrSi, FeCb, FeSi, FeMn | Electric | 16 |  |
| 38 | Ferroalloys Div. | L | Ashtabula, Ohio | FeTi, FeW, FeV, SiMn, other | Electric | 8 | 5 |
| 39 |  | L | Marietta, Ohio |  | Electric, electrolytic, vacuum | 11 |  |
| 40 | Mining & Metals Div. | S | Niagara Falls, N.Y. |  | Electric, Aluminothermic | 2 |  |
| 41 | Ferroalloys Div. | S | Portland, Oreg. |  | Electric | 2 | 1 |
| 42 |  | M | Sheffield, Ala. |  | Electric | 5 |  |
| 43 | Woodward Co. | M | Rockwood, Tenn. | FeMn, SiMn | Electric | 7 |  |
| 44 | Div. Mead Corp. | S | Woodward, Ala. | FeSi | Electric | 1 |  |
|  |  |  |  |  | Total | 145 | 13 |

[a]Plant size classification:
S-Up to 25,000 KW
M-25,000 to 75,000 KW
L-Over 75,000 KW

Table IV-2. FERROALLOY PLANTS AND NUMBER OF ELECTRIC FURNACES BY STATES (1971)

| State | Plants | No. furnaces | |
|---|---|---|---|
| | | Ferroalloy | Carbide |
| Ohio | 8 | 52 | 5 |
| Alabama | 6 | 12 | 0 |
| Pennsylvania | 5 | 0 | 0 |
| Tennessee | 4 | 14 | 0 |
| Oregon | 4 | 8 | 2 |
| West Virginia | 3 | 25 | 0 |
| New York | 3 | 6 | 0 |
| Kentucky | 2 | 11 | 4 |
| Iowa | 2 | 5 | 1 |
| Washington | 2 | 6 | 0 |
| Texas | 1 | 3 | 0 |
| South Carolina | 1 | 2 | 0 |
| Oklahoma | 1 | 0 | 1 |
| Mississippi | 1 | 0 | 0 |
| New Jersey | 1 | 1 | 0 |
| Totals | 44 | 145 | 13 |


WASH.
2
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IOWA
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OKLA.
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TEXAS
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N.Y.
3
PENN.
5
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N.J.
8
OHIO
W. VA.
3
VA.
1
KY.
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MISS.
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ALA.
6
S.C.
1

Figure IV-1. Ferroalloy producers, 1971.

## V. FERROALLOY MANUFACTURE

### A. DESCRIPTION OF PROCESSES[9,10,11]

Ferroalloy manufacturing processes are described in this section. Listed below are the processes and the product groups manufactured by each process.

| | |
|---|---|
| Submerged-arc furnace process - | Silvery iron (15-22% FeSi)<br>50% Ferrosilicon<br>65-75% Ferrosilicon<br>Silicon metal<br>Calcium silicon<br>Silicon-manganese-zirconium (SMZ)<br>High-carbon (HC) ferromanganese<br>Silicomanganese<br>Ferromanganese silicon<br>Charge chrome and HC ferrochrome<br>Ferrochrome-silicon<br>Calcium carbide |
| Exothermic process - | Low-carbon (LC) ferrochrome<br>LC ferromanganese<br>Medium-carbon (MC) ferromanganese<br>Chromium metal, FeTi, FeV and FeCb |
| Electrolytic process - | Chromium metal<br>Manganese metal |
| Vacuum furnace process - | LC ferrochrome |
| Induction furnace process - | Ferrotitanium |

### 1. Submerged-Arc Furnace Process

The general design of submerged-arc furnaces is basically the same throughout the industry. A schematic diagram of a submerged-arc furnace is shown in Figure V-1. The steel furnace shell is normally cylindrical with a flat bottom and is supported on an open foundation that permits

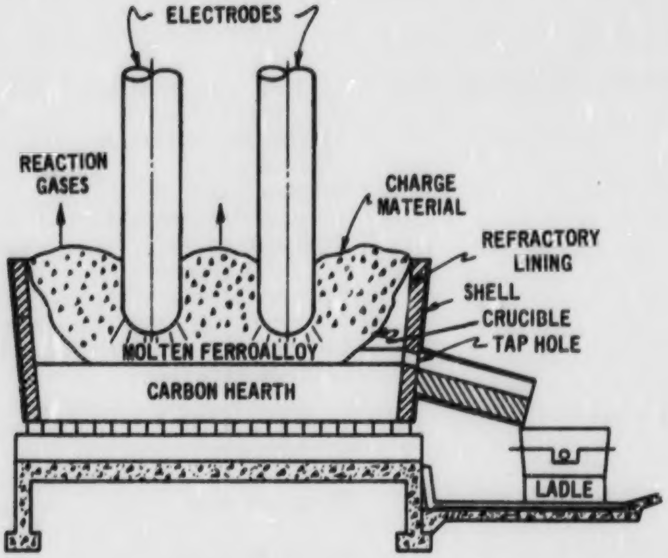
ELECTRODES
REACTION GASES
CHARGE MATERIAL
REFRACTORY LINING
SHELL
CRUCIBLE
TAP HOLE
MOLTEN FERROALLOY
CARBON HEARTH
LADLE

Figure V-1. Submerged-arc furnace for ferroalloy production.

air cooling and heat dissipation. The bottom interior of the steel shell is lined with two or more layers of carbon blocks sealed with mortar. The furnace shell's interior walls are lined with refractory or carbon brick. One or more tapholes for removing slag and metal are provided through the furnace shell at the hearth level. In some cases, the furnace is designed to rotate.

The furnace process is continuous. Power is continuously applied to the electrodes, and feed materials that consist mostly of reducing material (coal or coke) and ores may be charged to the furnace on either a continuous or an intermittent basis. Normally three electrodes are used and are suspended over the furnace hearth in a delta formation. They protrude into the furnace charge to a depth of 3 to 5 feet and their vertical movement is controlled by mechanical or hydraulic means. This electrode depth is continually varied as required to maintain a near-uniform electrical load. The trend is to use self-baking electrodes for new large furnaces. The major smelting occurs in the "reaction zones" surrounding the electrodes. This smelting utilizes carbon reduction of metallic oxides and continuously produces large quantities of carbon monoxide, in many cases in larger amounts than the metallic product. Other sources of primary gas are moisture in the charge materials, reducing agent volatile matter, thermal decomposition products of the raw ore, and intermediate products of reaction. The gas rising out the top of the furnace carries fume from the high-temperature regions of the furnace and also entrains the finer size constituents of the charge.

Submerged-arc furnaces have been generally built with open tops and the reaction gases burn on the surface of the charge. The combusted gases are vented to the atmosphere through roof monitors, or collected by a hood over the furnace crucible and directed by duct work to dust removal equipment or vented by stacks to the atmosphere. The furnace parts over the crucible, such as the electrode holders, the hangers, the current conductors, the contact plates, and the charging chutes, are exposed to the radiant heat of the furnace and hot furnace gases. These components must receive effective heat protection through the use of cooling water flowing through interior passages in the metal parts. Figure V-2 shows a cross section of a typical open furnace and some accessory equipment. Some ferroalloys, such as high silicons, require regular stoking and directed mix placement, which can only be performed in an open furnace.

Submerged-arc furnaces producing certain ferroalloys have water-cooled covers. The collected uncombusted gases are cleaned by venturi or centrifugal scrubbers, and the gases may be flared or used as fuel. In such furnaces, the raw materials required to produce the low-energy products do not tend to bridge excessively, and regular stoking of the charge is not necessary.

Submerged-arc furnaces generally operate continuously except for periods of power interruption or mechanical breakdown of components. Operating time averages 90 to 95 percent on an annual basis.

### 2. Exothermic Process

Several metals and low-carbon ferroalloys are produced by the exothermic process. However, it is used to a lesser extent than the submerged-arc furnace process. Most of the charge material used in the exothermic process may be first produced by the submerged-arc or open-arc furnaces. Silicon or aluminum, or a combination of the two, is the

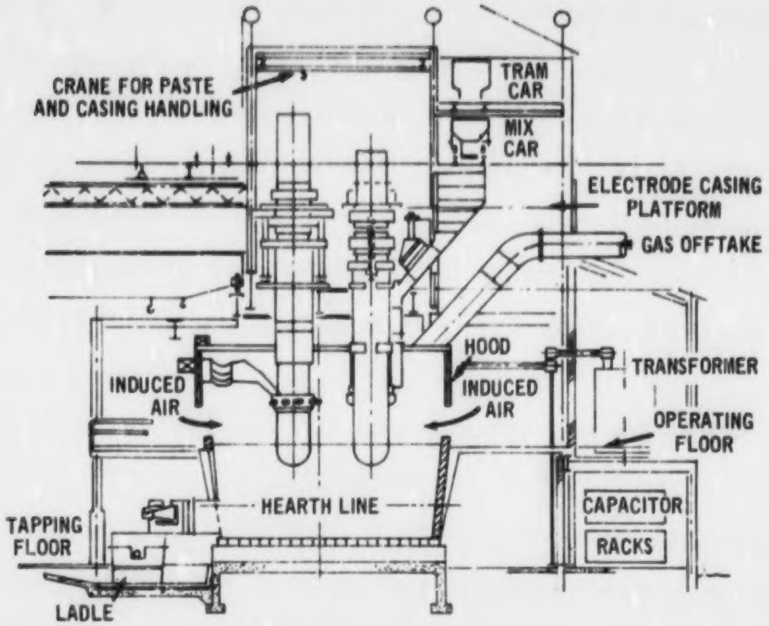
CRANE FOR PASTE
AND CASING HANDLING
TRAM
CAR
MIX
CAR
ELECTRODE CASING
PLATFORM
GAS OFFTAKE
HOOD
TRANSFORMER
INDUCED
AIR
INDUCED
AIR
OPERATING
FLOOR
HEARTH LINE
CAPACITOR
RACKS
TAPPING
FLOOR
LADLE

Figure V-2. Cross section of open furnace.

reducing agent. This agent reacts with the charge to remove oxygen, thus generating considerable heat; temperatures may reach several thousand degrees. Since the process is exothermic, the reduction can take place outside a furnace -- usually in ladles. The techniques employed are described in the following text.

a. Silicon Reduction - Two principal products, LC ferrochrome and LC or MC ferromanganese, are produced by silicon reduction. A flow diagram of a typical silicon reduction process for manufacturing LC ferrochrome is shown in Figure V-3. First, chromium ore and lime are fused together in a furnace to form a chrome ore/lime melt. Second, a known amount of the melt is poured into the No. 1 reaction ladle followed by a known quantity of molten ferrochrome-silicon previously produced in a No. 2 ladle. Ladle reaction results in a rapid reduction of the chrome from its oxide and the formation of LC ferrochrome and a calcium silicate slag.

Since the slag still contains recoverable chromium oxide, a second silicon reduction is made, in the No. 2 ladle, with molten ferrochrome-silicon from the submerged-arc furnace. Reaction in the No. 2 ladle produces the ferrochrome-silicon used in the No. 1 ladle for the next heat, and a throw-away slag with low chromium content. LC and MC ferromanganese are produced by a similar practice using a silicon-bearing manganese alloy for reduction.

The silicon reduction results in strong agitation of the molten bath and a rise in temperature. For about 5 minutes per heat the elevated temperature and agitation produce emissions whose characteristics are similar to those from submerged-arc furnaces.

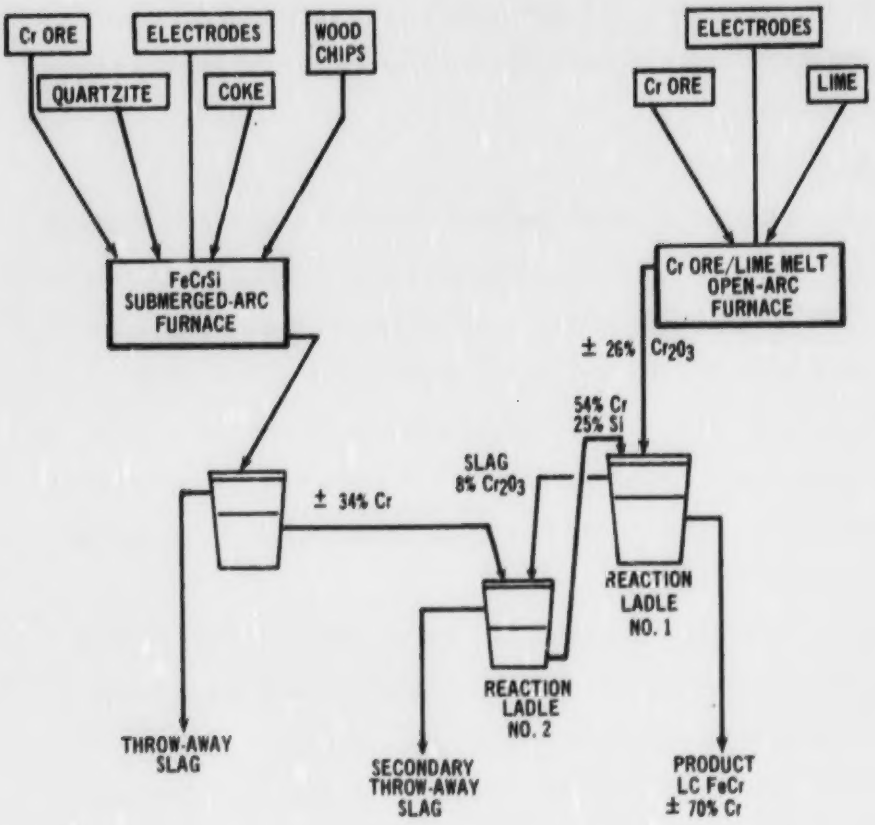
Cr ORE
ELECTRODES
WOOD CHIPS
QUARTZITE
COKE
FeCrSi SUBMERGED-ARC FURNACE
ELECTRODES
Cr ORE
LIME
Cr ORE/LIME MELT OPEN-ARC FURNACE
± 26% $Cr_2O_3$
54% Cr
25% Si
SLAG
8% $Cr_2O_3$
± 34% Cr
REACTION LADLE NO. 1
REACTION LADLE NO. 2
THROW-AWAY SLAG
SECONDARY THROW-AWAY SLAG
PRODUCT
LC FeCr
± 70% Cr

Figure V-3. Typical flow sheet for LC ferrochrome.

b. Aluminum Reduction - Aluminum reduction is used to produce chromium metal, ferrotitanium, ferrovanadium, and ferrocolumbium. Although aluminum is a more expensive reductant than carbon or silicon, the products are purer. Mixed aluminothermal-silicothermal processing is used for the production of ferromolybdenum and ferrotungsten. Usually such alloys are produced by exothermic reactions initiated by an external heat source and carried out in open vessels. Aluminothermal manganese is being replaced by electrolytic manganese. The high-temperature reaction of aluminum reduction produces emissions for a limited time similar to those produced by silicon reduction.

### 3. Electrolytic Process

The pure metals of manganese and chromium are now generally produced electrolytically. In this process, simple ions of the metal contained in an electrolyte of modest concentration are plated on cathodes by a low-voltage direct current. The pure metal, collected as a film about 1/8 inch thick on the cathode, is removed and prepared for shipment. Metal deposition usually occurs in a number of cells with multiple plates connected in a series of parallel electrical circuits; all are contained in a ventilated building.

Because electrolyte preparation is complex, feed materials require some chemical preprocessing. For example, manganese ores are calcined and leached (usually to form manganese sulfate), mixed with ammonium salts, and delivered in solution to the bath. The sources of the feed materials are ores, high-metal-oxide slags, and ferroalloys produced in submerged-arc furnaces.

The electrolytic process does not generate particulate emissions, but it does result in some minor emissions of ammonia or sulfur oxides. These emissions have not been quantified.

### 4. Vacuum and Induction Furnace Process

The vacuum furnace process for producing LC ferrochrome was developed commercially in the early 1950's. In this process, carbon is removed from HC ferrochrome in a solid state within vacuum furnaces (see Figure V-4) carefully controlled at a temperature near the melting point of the alloy. The process is based on the oxidation of HC ferrochrome by the oxygen in silica or chrome oxide. Carbon monoxide gas resulting from the reaction is pumped out of the furnace to maintain a high vacuum and to facilitate decarburization of the ferrochrome. Heat is supplied to the furnaces by electric resistance elements. The vacuum furnace process causes no particulate emissions. The small quantities of carbon monoxide gas that evolve from the reaction are withdrawn by a steam jet ejector

Induction furnaces, either low-frequency or high-frequency, are used to produce small tonnages of a few specialty alloys through remelting of the required constituents (see Figure V-5).

## B. METALLURGY OF THE PROCESSES[9,10,12,13]

Ferroalloys are usually produced by carbothermal smelting in electric submerged-arc furnaces. Depending on the product made, the raw materials used most often are quartz, manganese ore, chrome ore, scrap iron, and reducing agent. Sometimes wood chips are required for porosity within the furnace charge. The purpose of the reducing agent is to remove oxygen from the metallic oxide ore so that droplets of the metal fall to the hearth and form a metal pool. The reducing agent is usually in the form of lumpy or pea-size by-product coke and low-volatile coal. In the pro-

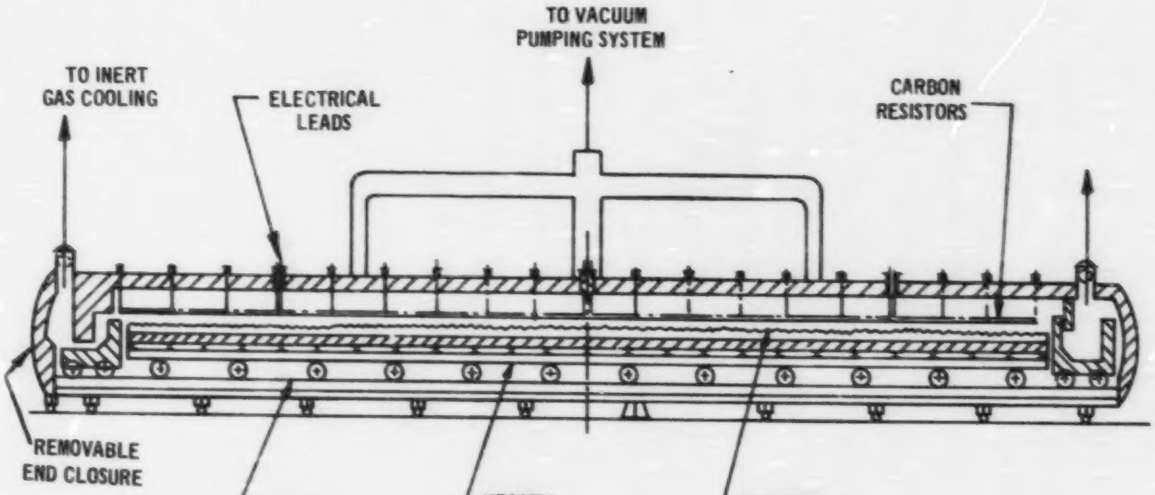
TO VACUUM
PUMPING SYSTEM
TO INERT
GAS COOLING
ELECTRICAL
LEADS
CARBON
RESISTORS
REMOVABLE
END CLOSURE
TRACK
HEARTH
CAR
FURNACE
CHARGE

Figure V-4. Simplex vacuum furnace for ferroalloy production.

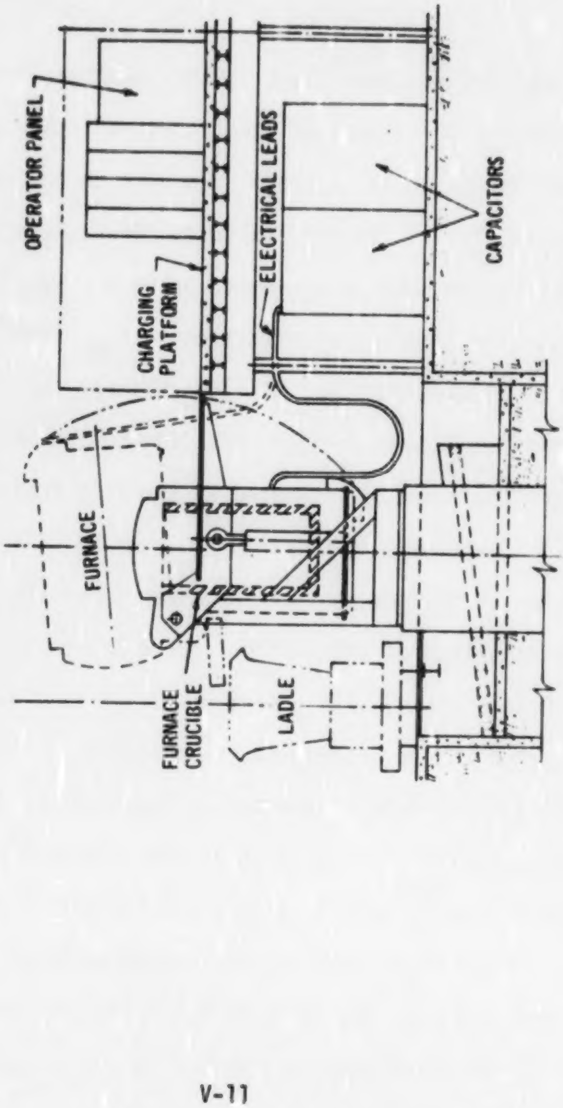
OPERATOR PANEL
CHARGING PLATFORM
ELECTRICAL LEADS
CAPACITORS
FURNACE
FURNACE CRUCIBLE
LADLE

Figure V-5. Induction melting furnace.

duction of certain types of products, however, silicon or aluminum is used as the reducing agent.

Iron content in the ferroalloy charge materials greatly facilitates the ferroalloy smelting operation. In the presence of iron, some of the nonferrous elements can be reduced by carbon at lower temperatures. Iron also serves as a collector for the alloying element and makes it easier to reduce.

Before smelting can take place in the submerged-arc furnace, the electrical energy must be changed to heat at extremely high temperatures. The conversion is due to the current flow through the resistance path of the charge materials between the electrode tips. Alternating current is used as the energy because of convenience and availability. With the use of such current, the tip of each electrode continually changes its polarity and an alternating current flows between the tips. The current path in the furnace establishes the reaction zone. The possible maximum internal temperature can be estimated by the fact that carbon vaporizes at 6620° to 6820° Fahrenheit.[9] Temperatures near this level are necessary for final reduction of the ores in the lower region of the furnace.

The upper portion of the furnace charge may be considered similar to a packed tower or bed, with a portion of the heat from the rising hot gases being transferred to the descending raw materials.[9] The area above the electrode tips contains unreacted and partially reacted raw materials. The lower parts of the vertically positioned electrodes are submerged into the mix to a depth of 3 to 5 feet and are within 3 to 6 feet of the hearth. If the electrodes are not submerged deeply enough, excessive fumes and poor operation will result. Molten alloy accumulates at the base of the electrodes in the furnace and is periodically removed through a taphole.

Simplified equations illustrating the manufacture of ferroalloys are as follows:

| Ore constituents | | Reducing agent | Heat | Molten alloy | | Furnace gas |
|---|---|---|---|---|---|---|
| $Cr_2O_3$ | + | 3C | $\longrightarrow$ | 2 Cr | + | 3 CO |
| MnO | + | C | $\longrightarrow$ | Mn | + | CO |
| $SiO_2$ | + | 2C | $\longrightarrow$ | Si | + | 2 CO |
| $Fe_2O_3$ | + | 3C | $\longrightarrow$ | 2 Fe | + | 3 CO |
| CaO | + | 3C | $\longrightarrow$ | $CaC_2$ | + | CO |

$$\left.\begin{array}{l} Al_2O_3 \\ CaO \\ MgO \\ SiO_2 \end{array}\right] \longrightarrow \text{Slag}$$

Reduction reactions require high temperatures, up to 2000°C. As shown in the equations, carbon monoxide gas is evolved from the smelting reaction. In the case of silicon metal, about 2 pounds of carbon monoxide are produced for each pound of metal; significant amounts of silicon monoxide are also produced as an intermediate.

## C. SOURCES, PREPARATION AND HANDLING OF RAW MATERIALS

The evaluation and selection of individual ores is highly technical and specialized. The ores must be analyzed not only for the primary chemical constituents but also for undesirable elements. Cost of various ores, including government tariffs and freight charges, is an essential consideration. Other considerations in the purchase of ores are their physical characteristics, ease of reduction, and analytical specifications necessary to meet customer requirements.

Most ores come to the market in the dressed state and are sold based on their content of the desired metal oxide, i.e., manganese oxide, chromium oxide, etc. In general, ores containing high percentages of metal oxides are easier to process and result in lower production costs than ores with lower percentages of metal oxides.

The United States is dependent almost entirely upon foreign sources of manganese and chromium ores. These ores are imported mainly from South America, Africa, Turkey, India, and Russia. Since the time interval between mining the ores and their receipt at ferroalloy plants is usually months, or even as long as a year, a substantial stock of manganese and chromium ores must be maintained. The general practice is to procure ores from familiar sources because the fundamental chemical composition and physical properties of known manganese and chromium ore deposits are reasonably well defined. Such ores have already demonstrated their suitability for the intended smelting process.

Chromium ores imported for ferroalloy production in the United States contain about 45 to 53 percent $Cr_2O_3$. The Mn content of the manganese ores ranges from 43 to 54 percent. Table V-1 shows typical chemical compositions of the three most widely used ores.

In addition to chromium and manganese ores, columbium-bearing ores or slags, titanium oxides, and zirconium oxides are also imported. The United States Bureau of Mines publishes information on ores imported for ferroalloy production (see Table V-2).

Commercial sources of vanadium- and tungsten-bearing ores exist in the United States. High-purity quartzes or quartzites with low alumina, and in some cases low iron oxide, are found in selected areas

Table V-1. CHEMICAL COMPOSITION OF ORES
(percent)

| Chemical constituent | Manganese ore[12] | Silicon ore[14] | Chromium ore[12] |
|---|---|---|---|
| Mn | 43 to 54 | | |
| $SiO_2$ | 4.15 | 98.5 | 1.2 |
| $Cr_2O_3$ | | | 45 to 53 |
| Fe | 1 to 2 | | 11 |
| $Al_2O_3$ | 1 to 3 | | 9.8 |
| MgO | 0.1 to 2 | | 16.6 |
| BaO | 1 to 3 | | |
| CaO | 1 to 3 | | |
| P | 0.18 | | |
| $H_2O$ | 5 to 16 | | |

Table V-2. PRINCIPAL CHEMICAL CONSTITUENTS OF IMPORTED CHROMIUM AND MANGANESE ORES[15]

| Composition of ore | 1970 | | 1965 | | 1960 | |
|---|---|---|---|---|---|---|
| | Metal contained, tons | Gross ore, tons | Metal contained, tons | Gross ore, tons | Metal contained, tons | Gross ore, tons |
| Chrome ore | | | | | | |
| Not more than 40% $Cr_2O_3$ content | 92,160 | 260,164 | 87,089 | 271,353 | 144,697 | 328,009 |
| More than 40%, less than 46%, $Cr_2O_3$ content | 154,414 | 349,471 | 210,564 | 480,285 | 222,215 | 483,332 |
| More than 46% $Cr_2O_3$ content | 335,196 | 645,302 | 319,393 | 599,025 | 142,581 | 426,714 |
| Totals | 581,770 | 1,294,937 | 617,046 | 1,350,663 | 509,493 | 1,238,055 |
| Manganese ore | | | | | | |
| More than 10%, less than 35%, Mn content | No data | No data | 12,000 | 36,000 | 1,000 | 3,000 |
| More than 35%, less than 47%, Mn content (Chem. & bat. grade) | 177,000 | 395,000 | 430,000 | 1,016,000 | 68,000 | 134,000 |
| More than 47% Mn content (metallurgical grade) | 669,000 | 1,340,000 | 1,395,000 | 2,839,000 | 1,013,000 | 2,141,000 |
| Totals | 846,000 | 1,735,000 | 1,837,000 | 3,891,000 | 1,082,000 | 2,276,000 |

of this country. A few high-quality limestone deposits are also available domestically.

Shipments of ore, plus the required quartzes or quartzites, lime, scrap steel turnings, reducing agents, etc., are generally transported to plants by railway or river barge. Ores are unloaded by traveling cranes or railroad-car dumpers and moved with belt conveyors to storage areas. Ores are stockpiled in large quantities depending on the furnace capacity, marketing situation, and storage capacity of the plant. A large inventory of stockpiles may be required for economic reasons. For example, a low-grade and a high-grade chromium ore may be blended to form the desired charge materials rather than use only the more expensive high-grade ore.

The furnace charge must be carefully prepared to manufacture a specific ferroalloy. Free moisture in the raw materials ranges from 10 to 20 percent. In some plants, raw materials are dried before they are fed to the furnaces.

Size of the ore is important; it should be neither too large nor too small. Oversize ores must be crushed to a suitable size. Fine ores, such as flotation concentrates, cannot be charged directly into a submerged-arc furnace because they lack porosity and do not allow the release of reaction gases. Dust losses from fine ores may be as high as 15 percent of the ore charged. However, when fine ores are charged into an open-arc furnace (melt furnace), the dust loss has been found to be much less. While work has been done to increase production by briquetting fine ores, the U. S. industry has had difficulty justifying the cost.

After preparation, the raw materials are conveyed to a mix house where they are weighed and blended. The weighed mix is then moved by conveyors, buckets, skip hoists, or cars to the hoppers above the furnaces, from where it may periodically be charged to the furnaces by gravity flow through chutes.

## D. PRODUCT SIZING AND HANDLING

Ferroalloys are marketed in a broad range of sizes depending on final usage, from pieces weighing 75 pounds to granules of 100 mesh or finer. Ferroalloys are intermediate products, and are usually melted and blended with molten metal. For this reason, the ferroalloy product size is important.

Molten ferroalloys from the submerged-arc furnaces are generally tapped into refractory-lined ladles or into molds or chills for cooling. The chills are low, flat, iron or steel pans that allow heat to dissipate rapidly from the molten metal. Calcium carbide is tapped into chills on either a continuous or an intermittent basis. After the ferroalloy has cooled to a workable temperature, it is cleaned of adhering slag and sized to market specifications.

Sizing consists of breaking the large ingots by drop weights or hammers, followed by crushing (with large jaw crushers, roll mills, or grinders) and screening. Conveyors and elevators move the product between the crushing and screening operations. Storage bins hold the finished or intermediate products.

Because acetylene gas can be formed with airborne moisture during sizing and handling of calcium carbide, proper ventilation is essential to prevent small pockets of acetylene gas from forming inside the equipment.

# VI. ATMOSPHERIC EMISSIONS

## A. SOURCES AND CHARACTERISTICS OF EMISSIONS

### 1. Sources of Emissions

Emissions occur from several areas of the production facility. Dust emissions result from handling of raw materials and from crushing, screening, drying, weighing, and mixing operations. Particulates mostly as fume, carbon monoxide (CO), and dust are emitted from the furnace. Fumes are also emitted during furnace tapping and ladle transfer operations. Figure VI-1 is a flow diagram of a ferroalloy production facility showing points of potential dust and fume emissions.

### 2. Sources and Characteristics of Emissions from Raw Materials Handling and Preparation

Raw materials are delivered to ferroalloy plants by ship, railroad cars, or trucks. Materials such as ores, quartz or quartzite, limestone, fine scrap steel, coke, coal, and wood chips are normally stored in separate storage piles. Materials range in size from 5 inches to 1/4 inch or finer and may include fines generated by handling and processing operations. To minimize dust entrainment by wind, raw material storage piles may be sheltered by block walls, snow fences, or plastic covers, or may possibly be sprayed with water.

Fugitive dust may be generated at the plant site by heavy vehicles used for loading, unloading and transferring material. These emissions may be minimized by using a wetting agent or paving the plant yard. Emissions also occur when raw materials are loaded from storage piles into trucks or gondola cars with cranes or ship loaders. Moisture in the raw materials, which may be as high as 20 percent, tends to minimize these emissions.

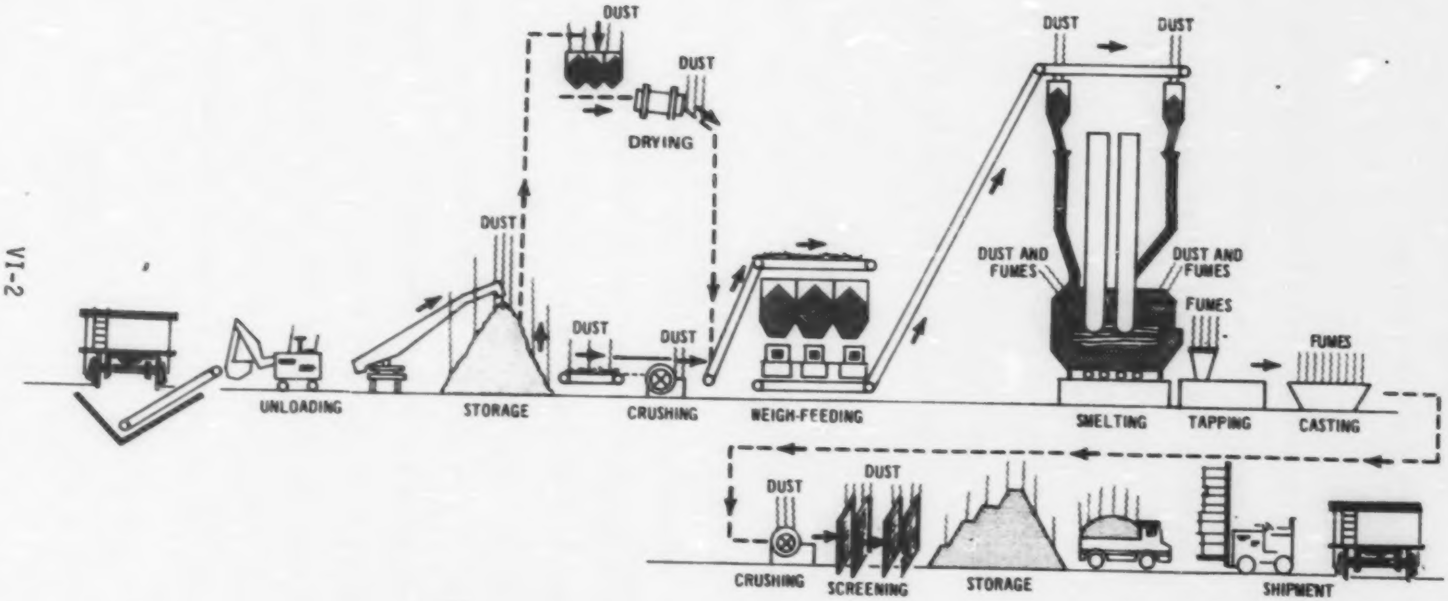
DUST
DUST
DRYING
DUST
DUST
DUST
DUST
DUST
DUST AND FUMES
DUST AND FUMES
FUMES
FUMES
UNLOADING
STORAGE
CRUSHING
WEIGH-FEEDING
SMELTING
TAPPING
CASTING
DUST
DUST
CRUSHING
SCREENING
STORAGE
SHIPMENT

Figure VI-1. Ferroalloy production flow diagram showing potential emission points.

The properties of particulates emitted into the atmosphere from raw material handling are similar to the natural properties of the ores. Dusts range in particle size from 3 to 100 microns. Bulk density of this dust when collected ranges from 35 to 100 pounds per cubic foot.

In a questionnaire survey, over 60 percent of the plants reported that some raw materials are pretreated before conveyance to the furnaces. Emission controls for preparation equipment are reported to be 90 to 99 percent effective for particulate removal.[16] (Scrubbers, cyclones, or baghouse collectors are used.)

Use of dry materials results in smoother furnace operation and reduced offgas volumes. Raw material moisture, as high as 20 percent, is sometimes reduced by the use of rotary or other type dryers. Unless adequate control equipment is installed, however these dryers may cause heavy particulate emissions. Raw materials charged to calcium carbide and chrome ore/lime melt furnaces are generally required to be dried.

### 3. Sources and Characteristics of Emissions from Submerged-Arc Furnace Process

By far the major pollution source in the ferroalloy production process is the furnace. Large quantities of CO gas and particulates are continuously produced by conventional submerged-arc furnaces. The CO gas, venting from the top of the furnace, carries fume from high-temperature regions of the furnace and entrains finer sized constituents of the mix. In many cases, the weight of carbon monoxide produced can exceed that of the metallic product.[17] Additional gas evolution is caused by moisture in the charge materials, volatile matter in the reducing agents, and thermal decomposition products of the raw ores.

Normally, these latter sources account for less than 30 percent of the CO production.

In an open furnace, CO and other combustibles in the furnace offgas burn with induced air at the charge surface, resulting in a large volume of high-temperature gas. In a covered furnace, most or all of the CO and other gases are withdrawn from the furnace without combustion.

Additional fumes occur at the furnace taphole. In some cases, gases issue from the taphole, but usually the emissions result from the molten alloy or slag. Most furnaces are tapped at 1 to 5-hour intervals with tapping periods lasting from 10 to 15 minutes or more. Taphole emissions occur 10 to 20 percent of the furnace operating time.

Additional reactions may be conducted in the ladle, such as chlorination, oxidation, slag-metal reactions, and stirring of molten metal with gas. In these cases, there may be fume generation in addition to the treatment gas, and possibly ejection of a portion of the molten contents in the ladle. Ladle treatment reactions have periodic emissions that have not been quantified.

Another source of pollution from furnaces equipped with self-baking electrodes is the fumes from the electrode paste during heating and baking. These fumes are minor and are usually vented directly to the atmosphere.

Water that leaks from electrode suspension equipment and other components above the furnace can result in some increased gas flow as steam or hydrogen.

Properties and quantities of emitted particulates depend upon the alloy being produced. Except for the larger dust particles of feed mix carried from the furnace, the particle fume size is generally below 2 microns (μ ) and ranges from 0.1 to 1.0 μ with a geometric mean of 0.3 to 0.6 μ , depending upon the ferroalloy produced.[17,18] In some cases, agglomeration does occur, and the effective particle size may be much larger. Grain loadings and flowrates depend on furnace type and hooding. Uncontrolled open furnaces have high flowrates with moderate grain loadings, while the gases from covered furnaces have flowrates as low as 1/50 that of open furnaces with high grain loadings.[17] In the dry state, the collected particulates are very light, and bulk density varies from 4 to 30 pounds per cubic foot.

Silicon alloys produce a gray fume containing a high percentage of amorphous silicon dioxide ($SiO_2$ ).[17,18] Some tars and carbon evolve, particularly from covered furnaces, from the coal, coke, or wood chips used in the furnace charge. These carbonaceous materials are burned at the charge surface in the case of the open furnace and in the case of the covered furnace are burned either by flaring or using as a waste heat fuel. Ferrochrome-silicon furnaces produce a $SiO_2$ emission similar to a ferrosilicon operation with some additional chromium oxides. Manganese operations produce a brown fume, which analysis indicates is largely a mixture of $SiO_2$ and manganese oxides.[17] Chemical analysis thus indicates fume composition is similar to oxides of the product being produced. An additional component of the fume is carbon from the reducing agents. Typical chemical analyses are given in Table VI-1.

4. Characteristics of Emissions from Other Ferroalloy Processes

a. The Exothermic Process - Metallic silicon, which is usually combined with other ferroalloys, and aluminum are intense deoxidizers and are used as the reducing agents in the exothermic process for making LC ferrochromium, MC and LC ferromanganese, ferromolybdenum, ferrovanadium, ferrotitanium, and

Table VI-1. TYPICAL FURNACE FUME CHARACTERISTICS[17]

| Fume characteristics | Furnace product | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 50% FeSi | SMZ[a] | SiMn[b] | SiMn[b] | FeMn | HC FeCr | Chrome ore-lime melt | Mn ore-lime melt[b] |
| Furnace type | Open | Open | Covered | Covered | Open | Covered | Open | Open |
| Fume shape | Spherical, sometimes in chains | Spherical, sometimes in chains | Spherical | Spherical | Spherical | Spherical | Spherical and irregular | Spherical and irregular |
| Fume size, microns | | | | | | | | |
| Maximum | 0.75 | 0.8 | 0.75 | 0.75 | 0.75 | 1.0 | 0.50 | 2.0 |
| Most particles | 0.05 to 0.3 | 0.05 to 0.3 | 0.2 to 0.4 | 0.2 to 0.4 | 0.05 to 0.4 | 0.1 to 0.4 | 0.05 to 0.2 | 0.2 to 0.5 |
| X-ray diffraction | | | | | | | | |
| Primary | ← All fumes were primarily amorphous → | | | | | | | |
| Trace constituents | FeSi<br>$FeSi_2$ | $Fe_3O_4$<br>$Fe_2O_3$<br>Quartz<br>SiC | $Mn_3O_4$<br>MnO<br>Quartz | Quartz<br>SiMn<br>Spinel | $Mn_3O_4$<br>MnO<br>Quartz | Spinel<br>Quartz | Spinel | CaO |
| Chemical analysis, percent | | | | | | | | |
| $SiO_2$ | 63 to 88 | 61.12 | 15.68 | 24.60 | 25.48 | 20.96 | 10.86 | 3.28 |
| FeO | | 14.08 | 6.75 | 4.60 | 5.96 | 10.92 | 7.48 | 1.22 |
| MgO | | 1.08 | 1.12 | 3.78 | 1.03 | 15.41 | 7.43 | 0.96 |
| CaO | | 1.01 | - | 1.58 | 2.24 | - | 15.06 | 34.24 |
| MnO | | 6.12 | 31.35 | 31.92 | 33.60 | 2.84 | - | 12.34 |
| $Al_2O_3$ | | 2.10 | 5.55 | 4.48 | 8.38 | 7.12 | 4.88 | 1.36 |
| LOI[d] | | - | 23.25 | 12.04 | - | - | 13.86 | 11.92 |
| Total Cr as $Cr_2O_3$ | | - | - | - | - | 29.27[c] | 14.69 | - |
| SiC | | 1.82 | - | - | - | - | - | - |
| $ZrO_2$ | | 1.26 | - | - | - | - | - | - |
| PbO | | - | 0.47 | - | - | - | - | 0.98 |
| $Na_2O$ | | - | - | 2.12 | - | - | 1.70 | 2.05 |
| BaO | | - | - | - | - | - | - | 1.13 |
| $K_2O$ | | - | - | - | - | - | - | 13.08 |

[a] Si - 60 to 65%; Mn - 5 to 7%; Zr - 5 to 7%

[b] Manganese fume analyses in particular are subject to wide variations, depending on the ores used.

[c] Fumes from open furnace contain less chrome oxide.

[d] LOI is loss on ignition at 1000°C.

other alloys that are produced in minor quantities.

Oxide fumes, similar in physical characteristics to those from the submerged-arc furnace, are emitted from the reaction ladle or furnace while the reducing agent is being charged. These emissions are caused by the strong agitation and rapid temperature rise of the molten bath during the initial reaction which lasts from 5 to 15 minutes. The entire heat cycle is about 1-1/2 to 2 hours. Therefore, atmospheric emissions from the exothermic reactions take place during about 10 percent of the cycle time.

The quantity of emissions from the exothermic reaction ranges from 20 to 40 pounds of particulates per ton of ferroalloy produced. The total tonnage of ferroalloys made by the exothermic process amounts to 200,000 to 300,000 tons per year or 10 to 15 percent of the total ferroalloy production in the United States.

b. The Electrolytic Process - Chromium, manganese, and manganese dioxide are products of the electrolytic process as used in the ferroalloy industry. Only six such electrolytic operations exist in the United States. Essentially no particulate or gaseous emissions result from the ambient-temperature electrolysis of the aqueous sulfate solutions used in these installations.

c. Vacuum and Induction Furnace - Although it does not appear that any significant emissions to atmosphere occur from the vacuum furnace or induction furnace processes, such emissions have not been quantified. Ferroalloys are made by these processes in fewer than 5 locations in the United States.

### 5. Characteristics of Emissions from Product Sizing

Ferroalloys are marketed in sizes ranging from 75-pound pieces to fine powders. Because ferroalloys have various degrees of hardness, several types of crushers and screens are employed for breaking the ferroalloys into smaller pieces and separating the broken pieces into different product sizes. The breaking process generates some undersize pieces and airborne dust as well. Most of the metallic dust generated from breaking and screening is in the range of 3 to 100 microns.[19] The amount of dust emitted to the atmosphere from these casting, breaking, and screening operations has not been quantified, but is substantially less than that of furnace emissions. About half of the ferroalloy plants have dust-abatement equipment for these operations.

## B. QUANTITIES OF EMISSIONS

### 1. Variability of Furnace Emission Rate During Normal Operations

Emission rates will vary with (1) type of alloy produced, (2) process (i.e., continuous or batch), (3) choice and size of raw materials, (4) operating techniques, (5) furnace size, and (6) maintenance practices.

Silicon alloys provide a good example of emissions varying with product. The emission of $SiO_2$ fumes increases directly with increasing silicon content of the product. Therefore, a silicon-metal furnace emits substantially more $SiO_2$ fumes than an equivalent-size 50-percent-ferrosilicon furnace. In addition, the higher ferrosilicon operations (75 percent Si and above) are known as "hot" operations; i.e., the gas is emitted at a high temperature and the furnace is subject to increased blows compared to lower silicon alloys. Blows are jets of extremely hot gas that issue from the high-temperature reaction zone and flow upward around the electrodes at high velocity. Higher silicon operations are also subject to hearth buildups of silicon carbide; more emissions occur under these conditions because the electrodes are operated at higher positions.

Manganese ores may contain significant amounts of water and higher manganese oxides that dissociate to lower oxides and oxygen at temperatures below 1000°C. A manganese furnace can thus be subject to "rough" operation. Sudden releases of gas can cause substantial ejection of mix from the furnaces. Silicomanganese furnaces are also subject to "slag boils," in which slag rises up to cover the top surface of the charge, impeding mix delivery and the uniform passage of gas through the charge.[17] These adverse furnace conditions can be minimized by careful furnace operation.

In furnaces with self-baking electrodes, the oxidizing atmosphere can result in "fluting" or grooving of the electrodes along the metal fins, forming direct gas passages through which fumes may escape from the high-temperature zone of the furnace.[17]

Emissions from batch-operated open-arc furnaces vary during the melt cycle. Following sudden addition of mix containing volatile or reactive constituents (coal, moisture, aluminum, etc.) to a hot furnace crucible, violent gas eruptions can occur. This is best exemplified by the manganese ore/lime melt furnace from which momentary gas flow following mix addition can be five times the average flow. Under these conditions, temperature, dust loading, and gas flow all peak simultaneously. In contrast, chromium ore/lime melt furnaces, to which few or no gas-releasing materials are fed, are not subject to this violent behavior.

The size of raw materials has some bearing on emission rate variability. A significant contributor to rough furnace operation may be the presence of fines or dense material in the feed. Such materials promote bridging and nonuniform descent of the charge, which may cause gas channels to develop.

The collapse of a bridge causes a momentary burst of gases. A porous charge promotes uniform gas distribution and decreases bridging. For some products, economics dictates the use of raw materials with more fines or with more volatile matter than desirable. Each of these factors has an adverse effect on the smooth operation of the furnace, and consequently emissions may increase if the raw materials are not pretreated.

Differences in operating techniques can have a significant effect on emissions. The average rate of furnace gas production is directly proportional to electrical energy input, so that a higher load on a given furnace normally causes a proportional increase in emissions.[20] In some cases, emissions increase at a rate greater than the load increase due to rough operation and inadequate gas withdrawal.

Operating with insufficient electrode immersion increases the furnace gas temperature and fume content and may be above the capacity of an improperly designed air pollution control system.[9] Higher voltage operation for a given furnace promotes higher electrode positions and can promote increased fume emissions.

For some operations, especially silicon metal production, the charge must be stoked to break up crusts, cover areas of gas blows, and permit the flow of reaction gases. Therefore, emissions can be a function of how well and how often the furnace is stoked.

Semi-enclosed furnaces are designed to collect most of the furnace gases. Poor mix placement or insufficient mix delivery can, however, cause the release of heavy fumes around the electrodes.

Design and maintenance practices may significantly affect emissions from covered furnaces because materials may accumulate under the cover and in gas takeoff ducts reducing the gas-withdrawal capacity of the exhaust system. If gas passages in the control equipment are plugged on either open or covered furnaces, gas capture will be less efficient.

### 2. Variability of Furnace Emission Rates During Shutdowns and Startups

Because of the complexity of the heavy mechanical and electrical equipment associated with a modern submerged-arc furnace, close supervision and maintenance are required to prevent frequent furnace shutdowns. The furnaces are designed to operate continuously to maintain satisfactory metallurgical and thermal equilibriums.

Normal furnace shutdowns on an annual basis may average 5 to 10 percent of the operating time and are caused by such situations as electrode installations, prevention and repair of water leaks at electrode contact plates, mix chute failures, furnace hood or cover failures, taphole problems, electrical or other utility failures, crane failures, pollution control, and ladle or chill problems. In general, furnace interruptions are relatively short in duration, usually not more than several hours. Following such interruptions, the furnace usually returns to normal operation with normal emissions in a period of time approximately equal to the length of the interruption.

Greater-than-normal emissions may occur when power is returned to the furnace after a lengthy interruption caused by a major furnace operational problem. These problems may include electrode failure that makes it necessary to dig out an electrode stub or to bake at a reduced load for self-baking electrodes, serious mixture blows of the furnace, metallurgical problems that require a furnace burndown to return it to normal operation, serious water leaks that flood the furnace with water, furnace hearth failure, major taphole problems, and transformer or major electrical system failure. When starting up a new furnace, one with a cleaned-out hearth, or one with a cold hearth after a long shutdown, heavier-than-normal emissions may last from a few days up to a month before the furnace operates in an optimum manner.

Semi-enclosed furnaces are operated with the cover doors open and mix seals empty during startups, shutdowns, and electrode burndowns. Totally enclosed furnaces are also operated with cover doors open during these operations. Consequently, higher-than-normal emissions may occur during these periods. However, open furnaces with air pollution control devices should emit no additional pollutants during these shutdown or startup periods because the control system remains in operation during these times.

### 3. Data from Questionnaires

a. Quantities of Emissions from Electric Furnaces Reported - Ferroalloy manufacturers have voluntarily provided information on 120 submerged-arc furnace operations representing about 70 to 80 percent of the furnaces in the United States. The information submitted in response to questionnaires includes the quantities of particulate emissions based on test data or estimates from ferroalloy smelting, and performance data and estimates for emission control equipment. Table VI-2 shows the types of control equipment now in general use in the United States. In 1971 approximately 50 percent of the furnaces were equipped with one or more of these types of control devices.[16]

Table VI-2. TYPES OF CONTROL SYSTEMS USED ON FERROALLOY FURNACES IN THE UNITED STATES[16]

| Semi-enclosed and covered furnaces with withdrawal and cleaning of unburned gases | | Open furnaces with withdrawal and cleaning of burned gases | |
|---|---|---|---|
| Control device | Products | Control device | Products |
| Wet scrubbers | HC ferromanganese | Wet scrubbers | 50 to 75% Ferrosilicon |
| | 50 to 75% Ferrosilicon | | Silicomanganese |
| | Calcium carbide | | HC ferrochrome |
| | HC ferrochrome | | Ferrochrome-silicon |
| | | Cloth filters | Silicomanganese |
| | | | Ferromanganese silicon |
| | | | 75% and higher grades of ferrosilicon |
| | | | Silicon metal |
| | | | Ferrochrome-silicon |
| | | Electrostatic[a] precipitator | HC ferrochrome |
| | | | Ferrochrome-silicon |

[a] Only two electrostatic precipitators are currently used in the United States and were installed after the questionnaire survey was completed.

Because the quantity of emissions will vary with the product, the following 14 products have been categorized into four product groups:

Silicon Alloys

- Calcium Silicon
- Silicon metal
- 65-75% Ferrosilicon
- 50% Ferrosilicon
- SMZ (Silicon Manganese Zirconium)
- Silvery Iron (15-22% FeSi)

Manganese Alloys

- High-Carbon (HC) Ferromanganese
- Ore/lime melt (used to make MC ferromanganese)
- Silicomanganese
- Ferromanganese silicon

Chrome Alloys

- Ferrochrome-silicon
- HC Ferrochrome & charge ferrochrome
- Ore/lime melt (used to make LC ferrochrome)

Other Products

- Calcium Carbide

The questionnaires submitted provide estimates & data about gaseous emission characteristics and indicate the variations in particulate emission rates for each product. This information has been tabulated and summarized in Tables VI-3 through VI-8.

Table VI-3 provides estimated uncontrolled emission factors for each product along with the corresponding production factors. The production factors show the average amount of electrical energy required to produce one ton of ferroalloy and the number of tons of feed mixture needed to produce one ton of ferroalloy. These production factors are averages and may vary up to 15 percent. Using losses reported by questionnaires, typical energy consumption figures, and typical feed charge figures, caluclations have been made to determine the

## Table VI-3. PRODUCTION AND EMISSION FACTORS FOR UNCONTROLLED OPEN FURNACES[16]

| Product | Production factors | | Emission factors | | |
|---|---|---|---|---|---|
| | Electrical Energy, mw-hr/ton product (average) | Ratio, tons charge/ ton product (average) | Particulates, lb/ton product | Particulates, lb/ton charge | Particulates, lb/mw-hr |
| Silicon alloys | | | | | |
| CaSi | 11.8 | 3.9 | 1343 | 344 | 114 |
| Si | 14.0 | 4.9 | 1200[a] | 245[a] | 86[a] |
| SMZ | 8.8 | 4.5 | No data[b] | No data[b] | No data[b] |
| (65-75%)FeSi | 8.8 | 4.5 | 915 | 203 | 104 |
| 50% FeSi | 5.0 | 2.5 | 446 | 179 | 89 |
| Silvery iron (15-22% FeSi) | 2.6 | 1.8 | 116 | 64 | 45 |
| Manganese alloys | | | | | |
| FeMnSi | 5.4 | 4.3 | 315 | 73 | 58 |
| SiMn | 4.4 | 3.1 | 219 | 71 | 50 |
| (HC) FeMn | 2.4 | 3.0 | 335 | 84 | 62 |
| Mn ore/lime melt | 1.6 | 3.5 | 133 | 38 | 83 |
| Chrome alloys | | | | | |
| FeCrSi | 7.4 | 3.4 | 831 | 244 | 112 |
| (HC) FeCr and charge chrome | 4.2 | 4.0 | 335 | 84 | 62 |
| Cr ore/lime melt | 1.2 | 1.2 | 11 | 9 | 9 |
| Other | | | | | |
| $CaC_2$ | 2.6 | 1.6 | No data[b] | No data[b] | No data[b] |

[a] Questionnaire data not conclusive. Numbers presented are estimates by the ferroalloy industry.

[b] No uncontrolled particulate emission reported in questionnaires.

average emission factor in pounds of particulates per ton of ferroalloy produced, pounds of particulates per ton of charge material to the furnace, and pounds of particulates per megawatt-hour electrical input. The emission factor is usually in the high range for those ferroalloys that require the largest amount of electrical energy to produce a ton of product. The products in each product group have been arranged in descending order of the amount of electrical energy input to determine if there is also a descending order in the amount of emissions. Questionnaire data were not sufficient to determine a definite correlation for some product groups, but a direct relationship was noted in most other instances. The summary calculated from the questionnaires shows that particulate emission factors, in pounds per megawatt-hour ranged from a high of 114 for CaSi down to 9 for the chrome ore/lime melt. The particulate emission factor for silicon alloy products increases when the silicon content in the product is increased. In addition, the emission factor of particulates per ton of silicon metal may vary considerably due to normal swings in silicon recovery. Normally silicon is recovered from the silicon dioxide charged to the furnace with an efficiency ranging from 70 to 80 percent. Based on one ton of $SiO_2$ charged, the theoretical calculations for silicon metal recovered and the associated silica fumes are shown:

Basis: One ton of $SiO_2$ charged to silicon furnace

| Recovery of Si from $SiO_2$ % | Si produced, lb | Loss of $SiO_2$, % | $SiO_2$ fumes[a] Theoretical | |
|---|---|---|---|---|
| | | | LB/ton product | lb/mw[b] |
| 70 | 654 | 30 | 1,835 | 131 |
| 75 | 700 | 25 | 1,429 | 102 |
| 80 | 746 | 20 | 1,070 | 76 |

[a] Assumes all fumes produced are $SiO_2$.

[b] This theoretical emission rate is based on an average production factor of 14 mw-hr per ton silicon produced.

For 50 percent ferrosilicon production, metallurgical results indicate a normal silicon recovery from 90 to 95 percent. Based on one ton of $SiO_2$ charged and a product analysis of 48.5 percent Si, the theoretical calculations for metal produced and the associated silica fumes are shown below:

Basis: one ton $SiO_2$ charged to 50% FeSi furnace

| Recovery of Si from $SiO_2$, % | Si produced, lb | Loss of $SiO_2$, % | $SiO_2$ fumes[a] (Theoretical) | |
|---|---|---|---|---|
| | | | lb/ton product | lb/mw[b] |
| 90 | 1,732 | 10 | 231 | 46 |
| 95 | 1,828 | 5 | 109 | 22 |

[a] Assumes all fumes produced are $SiO_2$.

[b] This theoretical rate is based on an average production factor of 5 mw-hr per ton FeSi produced.

The potential yearly quantities of particulate emissions can be estimated by using emission factors and known production figures. These calculations for 1971 are shown in Table VI-4. If all furnaces had been uncontrolled, total emissions for 1971 would have been 342,000 tons. This figure is slightly higher than that reported in a study made for the year 1968 by a contractor,[20] who estimated potential emissions as 250,000 tons and actual emissions, based on 80 percent control for 50 percent of the furnaces, as 150,000 tons. The difference between the two studies is primarily due to the use of different emission factors and the possible exclusion of calcium carbide in the 1968 estimate. The emission factors used for the 1968 estimate were determined from fewer data, some of which differed widely from those used in this study.

Table VI-5 summarizes questionnaire data on uncontrolled emissions from open furnaces. It shows the reported range of concentrations in grains per standard cubic foot (gr/scf) and mass emission rates in pounds per megawatt-hour (lb/mw-hr) coming off the furnace. These ranges are based on particulate emission tests and estimates. The highest reported uncontrolled mass emission rates are from the silicon alloy group of furnaces and range from 20 up to 324 lb/mw-hr. Although emissions of this high magnitude are not likely to occur, they may do so for a short period of time. Likewise some of the low figures in this group, i.e., 21 lb/mw-hr for a silicon furnace, appear much too low and unlikely when compared to the average figures shown in Table VI-3. The manganese alloy furnaces reportedly have the second highest uncontrolled mass emission rates, ranging from 14 up to 191 lb/mw-hr.

Table VI-6 summarizes questionnaire data on controlled emissions from open furnaces. As can be seen, very few data were reported. There are

Table VI-4. POTENTIAL PARTICULATE EMISSIONS (1971)

| Product | Production, net tons[a] | Uncontrolled emission factors, lb/ton alloy | Potential emission, tons/yr |
|---|---|---|---|
| **Silicon alloys** | | | |
| CaSi | 10,309 | 1,343[b] | 6,900 |
| Silicon metal | 88,888 | 1,200[c] | 53,300 |
| 65-90% FeSi | 109,951 | 673[c] | 37,000 |
| 50% FeSi | 377,403 | 446[b] | 84,200 |
| Silvery iron (15-22% FeSi) | 94,801 | 116[c] | 4,700 |
| | | | 186,100 |
| **Chrome alloys** | | | |
| FeCrSi | 66,685 | 831[b] | 27,700 |
| HC FeCr | 113,664 | 335[b] | 19,000 |
| LC FeCr | 96,611 | 60[d] | 2,900 |
| | | | 49,600 |
| **Manganese alloys** | | | |
| HC FeMn | 266,376 | 335[b] | 44,600 |
| LC FeMn | 106,019 | 133[b] | 7,000 |
| FeMnSi | 44,818 | 315[b] | 7,000 |
| SiMn | 150,383 | 219[b] | 16,500 |
| | | | 75,100 |
| **Other** | | | |
| $CaC_2$ | 625,000[e] | 100[c] | 31,200 |
| Totals | 2,150,910 | | 342,000 |

[a] Price-Waterhouse data.

[b] Emission factors determined from questionnaire data.

[c] Estimates.

[d] Emission occurring from ladle reactions.

[e] Department of Commerce, Census Bureau.

Table VI-5. RANGES OF UNCONTROLLED PARTICULATE EMISSIONS FROM OPEN FURNACES[16]

| Product | No. of open furnaces reported[a] | Range of emissions | |
|---|---|---|---|
| | | gr/scf | lb/mw-hr |
| Silicon alloys | | | |
| CaSi | 3 | 0.33 to 0.91 | 111 to 115 |
| Silicon | 12 | 0.15 to 1.1 | 21 to 323 |
| 65-75% FeSi | 6 | 0.16 to 0.25 | 40 to 191 |
| 50% FeSi | 12 | 0.30 to 1.3 | 20 to 324 |
| SMZ | 1 | 0.36 | 25 |
| Silvery iron (15-22% FeSi) | 4 | 0.30 to 0.7 | 20 to 70 |
| Manganese alloys | | | |
| FeMnSi | 1 | 1.0 | 58 |
| SiMn | 12 | 0.17 to 4.0 | 43 to 147 |
| HC FeMn | 4 | 0.05 to 4.0 | 14 to 191 |
| Mn ore/lime melt | 4 | NR[b] | NR |
| Chrome alloys | | | |
| FeCrSi | 15 | 1.05 to 1.86 | 42 to 180 |
| HC FeCr | 3 | 1.07 to 1.60 | 62 to 117 |
| Charge chrome | 3 | NR | NR |
| Cr ore/lime melt | 6 | 0.1 to 0.5 | 5 to 15 |
| Other | | | |
| $CaC_2$ | None | -- | -- |

[a] Includes emission data from open furnaces equipped with control devices. (Inlet data only to control devices)

[b] NR - none reported.

### Table VI-6. RANGES OF CONTROLLED PARTICULATE EMISSIONS REPORTED FOR CONTROL DEVICES SERVING OPEN FURNACES[16]

| Product | No. of control systems reported | Type of control | Range of emissions gr/scf | Range of emissions lb/mw-hr |
|---|---|---|---|---|
| Silicon alloys | | | | |
| CaSi | 0 | None | -- | -- |
| Silicon | 3 | Baghouse | NR[a] | NR |
| 65-75% FeSi | 1 | Baghouse | NR | NR |
| 50% FeSi | 1 | Baghouse | NR | NR |
| SMZ | | None | -- | -- |
| Silvery iron (15-22% FeSi) | | None | -- | -- |
| Manganese alloys | | | | |
| FeMnSi | 1 | Baghouse | NR | NR |
| SiMn | 3 | Scrubber | 0.02 to 1.0[b] | 0.76 to 37[b] |
| | 2 | Baghouse | NR | NR |
| HC FeMn | 1 | Scrubber[c] | 1.0[b] | 49[b] |
| | 1 | Baghouse | NR | NR |
| MC & LC FeMn | | Baghouse | NR | NR |
| Chrome alloys | | | | |
| FeCrSi | 1 | Scrubber | 0.1 | 1.9 |
| HC FeCr and charge chrome | 1 | Scrubber | 0.02 | 1.1 |
| Cr ore/lime melt | 0 | None | -- | -- |
| Other | | | | |
| $CaC_2$ | 0 | None | -- | -- |

[a] NR - none reported (collection efficiency reported as 99 percent plus.)

[b] High figures reported not typical of scrubbers serving ferroalloy furnaces.

[c] Scrubber homemade.

several control systems equipped with baghouses none of which reported outlet emission data. Apparently, these data are lacking because it is difficult to conduct stack tests on the open type of baghouse that is typical in the ferroalloy industry. The lowest reported mass emission rate from controlled open furnaces was 0.76 lb/mw-hr from a venturi scrubber serving a silicomanganese furnace. The lowest reported outlet concentration was 0.02 gr/scf, also from the same scrubber. This scrubber was later tested by EPA, and the results averaged 0.33 lb/mw-hr and 0.01/gr/scf.

Table VI-7 provides information on the ranges of particulate emissions reported for semi-covered furnaces with mix seals. Although there are a considerable number of semi-covered furnaces, all of which have scrubbers, very little information has been reported on the amount of particulate emitted into the atmosphere from these scrubbers. The lowest reported scrubber outlet emission rate was 0.13 lb/mw-hr. This was from a high-energy venturi scrubber operating at about 80 inches $H_2O$ pressure drop serving a large furnace producing 50 percent FeSi. Data submitted do not show how efficient a similar venturi scrubber system would be on a furnace in the chrome or manganese groups. Questionnaire data reported on outlet mass emission rates are insufficient to allow a comparison of controlled emissions for the different groups of alloys. However, tests made by EPA in Norway on covered furnaces producing FeMn and SiMn and equipped with venturi scrubbers were under 0.04 lb/mw-hr.[22] The table shows that the lowest reported loss for a Buffalo Forge centrifugal scrubber was 0.21 lb/mw-hr.

Table VI-7. RANGES OF PARTICULATE EMISSIONS REPORTED FOR SEMI-COVERED FURNACES WITH MIX SEALS[16]

| No. of furnaces reported | Product | Mix seal losses | | Scrubber inlet | | | Total scrubber inlet and mix seal losses | | Scrubber outlet | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | gr/scf | lb/hr | gr/scf | lb/hr | lb/mw-hr | lb/hr[a] | lb/mw-hr | gr/scf | lb/hr | lb/mw-hr |
| 7 | 50% FeSi | 0.04 to 0.27 | 14 to 115 | 5 to 22 | 160 to 680 | 8 to 44 | 421 to 795 | 11 to 51 | 0.08 | 5 | 0.13[b] |
| 3 | 65-75% FeSi | 0.1 to 0.25 | 44 to 110 | 20 to 22 | 343 to 750 | 36 to 50 | 389 to 860 | 41 to 58 | 0.3 to 0.4 | 5.2 to 13.7 | 0.5 to 0.9[c] |
| 4 | SiMn | 0.4 to 0.6 | 222 to 462 | 6 to 20 | 87 to 320 | 9 to 36 | 309 to 588 | 52 to 65 | NR | NR[d] | NR |
| 6 | FeMn | 0.05 to 0.4 | 16 to 278 | 4 to 30 | 58 to 515 | 10 to 74 | 208 to 592 | 36 to 81 | NR | NR | NR |
| 3 | HC FeCr | 0.12 to 0.15 | 41 to 50 | 20 | 353 | 29 to 35 | 394 to 403 | 34 to 39 | NR | NR | NR |
| 6 | $CaC_2$ | 0.05 to 0.1 | 34 to 55 | 15 to 25 | 210 to 450 | 22 to 30 | 399 to 505 | 23 to 33 | 0.13 | 21 | 0.21[c] |

[a] Low and high figures are not necessarily a total of previous columns.

[b] High-energy venturi scrubber.

[c] Centrifugal scrubbers.

[d] NR - not reported.

Dust and fume losses from mix seals on semi-enclosed furnaces may vary widely, as shown in Table VI-7. These emissions are uncontrolled. The mass emission rates of particulates from the mix seals varied from 14 to 462 lb/hr. The high measured loss of 462 lb/hr appears much too high in relation to the size of the furnace. The next highest reported loss was 278 lb/hr. The lowest reported loss of 14 lb/hr was from a 50 percent FeSi furnace. The lower reported emissions are probably due to better draft on the furnace produced by a scrubber system of adequate size and at the same time sufficient mix at the mix seals. Also, the furnace may have been operating smoothly during the stack test. The particulate concentrations of the uncontrolled gas stream coming from the mix seals ranged from 0.04 to 0.6 gr/scf. The concentrations of particulate in the gas stream from the mix seals are dependent upon the amount of dilution air added and do not reflect the mass emission rate.

Comparison of Tables VI-5 and VI-7 presents some indication that the quantity of particulate emissions from an uncontrolled semi-covered furnace is less than that from an uncontrolled open furnace. The ranges of total scrubber inlet and mix seal losses shown in Table VI-7 are lower than the ranges of uncontrolled losses shown in Table VI-5 for open furnaces.

The average exhaust system volumes on semi-enclosed and open furnaces shown in Tables VI-8 and VI-9 are based on standard cubic feet per minute per megawatt (scfm/mw). With gas volume rates based on this unit, these tables may be used to determine the gas volume expected for a typical air pollution control system serving a larger or smaller size furnace. For example, by using the unit volumetric rate of 220 scfm per megawatt for collected gas

### Table VI-8. AVERAGE EXHAUST-SYSTEM GAS VOLUMES FROM SEMI-ENCLOSED FURNACES[16]

| Product | Number of furnaces reported | Range of furnace sizes, mw | Type of control system | No. of control systems | Gases from fugitive exhaust system,[a] scfm/mw | Gases from air pollution control system, scfm/mw |
|---|---|---|---|---|---|---|
| HC FeMn | 7 | 5.9 to 13 | Scrubber | 7 | 8,600 | 220 |
| 65-75% FeSi | 3 | 9.5 to 15 | Scrubber | 3 | 4,000 | 210 |
| SiMn | 4 | 6 to 9.5 | Scrubber | 4 | 10,000 | 200 |
| HC FeCr | 4 | 10 to 25 | Scrubber | 3 | 3,750 | 190 |
| 50% FeSi | 7 | 11.3 to 38.5 | Scrubber | 7 | 2,650 | 180 |
| $CaC_2$ | 6 | 8.5 to 20.8 | Scrubber | 6 | 3,360 | 140 |

[a] Fugitive fumes are considered to be those fumes which are not collected by the primary air pollution control system and excludes tapping fumes.

Table VI-9. AVERAGE EXHAUST-SYSTEM GAS VOLUMES FROM OPEN FURNACES[16]

| Product | Number of furnaces reported, controlled & uncontrolled | Range of furnace sizes, mw | Type of control system | No. of control systems | Gases from uncontrolled exhaust system, scfm/mw | Gases from air pollution control system, scfm/mw |
|---|---|---|---|---|---|---|
| Silicon alloys | | | | | | |
| Silicon | 12 | 7 to 16 | Baghouse | 3 | 31,600 | 16,800 |
| CaSi | 3 | 8.7 to 12.5 | NR[a] | - | 29,200 | - |
| 75% FeSi | 6 | 9 to 30 | Baghouse | 1 | 11,500 | 18,600 |
| 50% FeSi | 12 | 7 to 35 | Baghouse | 1 | 10,700 | 9,200 |
| SMZ | 1 | 10 | NR | - | 5,700 | - |
| Silvery iron (15-22% FeSi) | 4 | 7.5 to 20 | NR | - | 9,700 | - |
| Manganese alloys | | | | | | |
| FeMnSi | 1 | 18 | Baghouse | 1 | NR | 6,700 |
| SiMn | 12 | 5 to 25 | Baghouse<br>Scrubber | 2<br>3 | 28,000<br>- | 12,200<br>4,800 |
| HC FeMn | 4 | 6.3 to 9.3 | Baghouse<br>Scrubber | 1<br>1 | 86,400<br>- | 13,200<br>5,500 |
| Mn ore/lime melt | 4 | 7 to 18.5 | Baghouse | 1 | NR | 8,100 |
| Chrome alloys | | | | | | |
| FeCrSi | 15 | 10 to 22 | Scrubber | 1 | 11,500 | 3,400 |
| HC FeCr and Charge chrome | 6 | 7 to 25 | Scrubber | 1 | 10,000 | 4,800 |
| Cr ore/lime melt | 6 | 7.3 to 16 | NR | - | 4,100 | - |

[a] NR-none reported.

from a semi-enclosed furnace producing ferromanganese as shown in the last column of Table VI-8, the volume of gas coming from a 30-mw size furnace is calculated to be 6,600 scfm. Similarly, from Table VI-9 it can be seen that the expected volumes of gas from the baghouse on a 30-mw open ferromanganese furnace would be approximately 396,000 scfm. Volumes from open furnaces will vary greatly, depending on the type of control equipment used, on the gas cooling method, and particularly on the proximity of the hooding to the furnace.

Table VI-10 shows the types of control systems used by the ferroalloy industry as reported in the questionnaires. For some products, three types of control systems are noted (as in the case of SiMn, where semi-enclosed furnaces are equipped with scrubbers, and open furnaces are equipped with a baghouse or a scrubber). Generalization about technology transfer cannot be made at this time because data are incomplete. Of the 47 control systems reported, 30 are scrubbers serving semi-enclosed furnaces making six different products. Since the 1970 questionnaire, SiMn is no longer made in a "semi-enclosed" furnace.

b. Reported Estimated Quantities of Emissions from Material Handling - Emissions to the atmosphere from other than the basic ferroalloy production process itself were reported for 16 ferroalloy plants. Summaries of estimated emissions from handling the raw materials (up to the furnace process) and from processing the ferroalloy product after the reduction state are shown in Tables VI-11 and VI-12.

Table VI-11 shows that the average raw material loss from receipt and storage is 0.1 percent of raw material handled. It can be assumed that a

Table VI-10. NUMBER OF EMISSION CONTROL SYSTEMS REPORTED IN USE IN 1970 BY TYPE AND PRODUCT[16]

| Product | No. of furnaces reported | Type of control system | | | Uncontrolled furnaces reported |
|---|---|---|---|---|---|
| | | Semi-enclosed furnace with scrubber | Open furnace | | |
| | | | Baghouse | Scrubber | |
| Silvery iron (15-22%FeSi) | 4 | | | | 4 |
| 50% FeSi | 19 | 7 | 1[a] | | 10 |
| 65-75% FeSi | 9 | 3 | 2 | | 4 |
| Silicon metal | 12 | | 3[b] | | 6 |
| SMZ | 1 | | | | 1 |
| Calcium silicon | 3 | | | | 3 |
| HC FeMn | 11 | 7 | 1 | 1 | 2 |
| SiMn | 16 | 4 | 2 | 3 | 7 |
| FeMnSi | 1 | | 1 | | - |
| Mn ore/lime melt | 4 | | 1 | | 3 |
| HC FeCr and charge ferrochrome | 9 | 3 | | 1 | 5 |
| Cr ore/lime melt | 6 | | | | 6 |
| FeCrSi | 15 | | | 1 | 14 |
| Calcium carbide | 6 | 6 | | | - |
| TOTALS | 116 | 30 | 11 | 6 | 65 |

[a] Serves two furnaces.

[b] One of these baghouses controls a building with four silicon furnaces.

### Table VI-11. ESTIMATES OF PARTICULATE EMISSION LOSSES FROM RAW MATERIAL HANDLING REPORTED FROM 16 FERROALLOY PLANTS[16]

(net tons/year)

| Plant code | Receipt and storage of raw materials | | | Preparation of raw materials[a] | | | Batching and delivery to furnace | | |
|---|---|---|---|---|---|---|---|---|---|
| | Quantity | Loss | Abatement equipment | Quantity | Loss | Abatement equipment | Quantity | Loss | Abatement equipment |
| 03528 | 330,000 | 300 | None | 10,000 | 100 | Yes | 330,000 | 300 | None |
| 03124 | 357,000 | 700 | None | 75,000 | 500 | None | 487,000 | 500 | None |
| 03957 | 28,100 | 70 | None | 0 | - | - | 28,030 | 70 | None |
| 01628 | 627,000 | 0 | None | 0 | - | | 627,000 | 0 | |
| 01325 | 170,000 | Non-noticeable | None | - | - | - | - | - | - |
| 09867 | 178,000 | Non-noticeable | None | 0 | - | - | 178,000 | 0 | - |
| 02397 | 64,800 | 0 | None | - | - | - | 64,800 | 0 | - |
| 05913 | 274,000 | 120 | None | 25,000 | 25 | None | 274,000 | 0 | None |
| 01382 | 155,000 | 300 | Yes | 17,500 | 45 | Yes | 150,000 | 200 | Yes |
| 04258 | 878,000 | 870 | None | 108,400 | 108 | Yes | 870,000 | 870 | None |
| 04687 | 600,000 | 600 | None | 175,000 | 1750 | Yes | 650,000 | 650 | None |
| 02391 | 800,000 | 800 | None | 40,000 | 400 | Yes | 700,000 | 700 | None |
| 09351 | 255,000 | 255 | Yes | 9,950 | 36 | Yes | 255,000 | 255 | Yes |
| 07561 | 400,000 | - | None | 192,000 | - | - | 400,000 | | None |
| 05876 | 300,000 | 1500 | - | 27,000 | 31 | - | 242,000 | 1200 | - |
| 06745 | 110,000 | 50 to 100 | - | 0 | - | - | 107,000 | 25 to 50 | - |
| | Average atmospheric loss from receipt and storage of raw materials = 0. 1% | | | Average atmospheric loss from preparation of raw materials = 0.1% | | | Average atmospheric loss from batching and delivery to furnace = 0.09% | | |

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[a] Preparation may include drying, crushing, or calcining.

part of this material loss enters the atmosphere as airborne dust and some of the heavier particles drop to the ground within the plant property. Raw material preparation equipment includes crushers for reducing large pieces, screens for size control, and dryers for moisture removal. As shown in the table, most of the preparation equipment has emission abatement equipment, and the questionnaires indicate that collection efficiency is from 90 to 99 percent. The average industry-wide dust loss from both controlled and uncontrolled material preparation operations is estimated as 0.1 percent. Questionnaire data show that when uncontrolled, the emissions to the atmosphere from raw material preparation equipment can range up to 1 percent of the material handled. Equipment for weighing the raw materials by batches and delivering them to the furnace in most cases did not have emission abatement equipment, and the dust loss to atmosphere was reported to be 0.1 percent. Because of insufficient data and the many differences of feed preparation from plant to plant, the overall average dust loss from material handling cannot be accurately derived as the sum of these three averages. However, another study indicates the overall losses from uncontrolled material handling are the same as those from the iron and steel industry -- 10 pounds per ton of metal produced or 0.5 percent.[20]

Table VI-12 shows that losses from treating molten ferroalloy in the ladle with chlorine or other gases amount to 0.47 percent of the product. This figure may be a little greater than normal, however, as the loss at one plant was much higher than at the other plants. The fume losses during ladle treatment are particulates which have characteristics similar to particulate emissions from ferroalloy furnaces.

Table VI-12. REPORTED ESTIMATES OF PARTICULATE EMISSION LOSSES FROM PRODUCT HANDLING IN FERROALLOY PLANTS[16,a] (net tons/year)

| Treatment of molten alloys | | | Casting of product | | | Crushing/grinding product | | |
|---|---|---|---|---|---|---|---|---|
| Quantity | Loss | Abatement equipment | Quantity | Loss | Abatement equipment | Quantity | Loss | Abatement equipment |
| 86,000 | 3,000 | None | 7,500 | 100 | None | 65,000 | 500 | Yes |
| 45,000 | 45 | None | 149,000 | 150 | None | 137,000 | 300 | Yes |
| 0 | - | | 11,500 | 25 | None | 11,475 | 115 | None |
| 7,200 | 75 | | 168,000 | - | - | 80,000 | 1,600 | Yes |
| 28,000 | 50 | | 28,000 | - | - | 8,000 | 200 | Yes |
| | - | - | 65,000 | - | None | 90,000 | 0 | Yes |
| 0 | - | - | 14,640 | 200 | Yes | 2,000 | 60 | Yes |
| 15,000 | 150 | None | 55,000 | 55 | Yes | 55,000 | 55 | Yes |
| - | - | - | 62,000 | 125 | Yes | 63,300 | 600 | Yes |
| 12,000 | 18 | Yes | 288,000 | 110 to 231 | Yes | 358,500 | 39 | Yes |
| 400,000 | 400 | None | 150,000 | 150 | None | 75,000 | 750 | Yes |
| 108,000 | 100 | None | 425,000 | 425 | None | 425,000 | 425 | Yes |
| 5,060 | - | None | 111,000 | - | Yes | 103,000 | 22 | Yes |
| 250,000 | | Yes | 200,000 | | None | 18,600 | - | - |
| 15,000 | - | - | 50,000 | - | - | 18,000 | 180 | Yes |
| 17,000 | Negl. | - | 17,000 | Negl. | - | 20,000 | 250 | Yes |
| Average atmospheric loss from treatment of molten alloys = 0.47% | | | Average atmospheric loss from casting of product = 0.01% | | | Average atmospheric loss from crushing/grinding product = 0.03% | | |

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[a] Plant code not shown; refer to Table VI-11.

The normal loss of molten ferroalloys to the atmosphere during casting operations is reported to be 0.01 percent, and the loss to atmosphere of metal fines through crushing and sizing operations reportedly averages 0.03 percent. About one-half of the crushing and sizing systems have emission control equipment.

4. Data from EPA Source Measurements

a. Quantities of Emissions from Electric Furnaces - The EPA Office of Air Programs awarded a contract to an independent company to perform a series of source emission tests on nine electric furnaces. These tests were arranged with the cooperation of The Ferroalloys Association. The following considerations were used in selecting the furnaces:

1. The furnaces tested should be equipped with effective emission control equipment.
2. At least one of every type of emission control system in service should be tested.
3. Since emissions will vary with different products, tests should be conducted on furnaces producing different products.
4. The tests should be distributed among the various producers to the fullest extent possible.
5. A limited number of tests on furnaces with no emission control equipment should be made to verify the questionnaire data and estimates.

To meet all the requirements of this plan, the original schedule called for testing a total of 17 furnaces at 10 locations. However, time and cost considerations allowed testing of only nine furnaces at seven U. S. plants over a 14-month period. Seven of the nine furnaces tested had emission control equipment. In addition, tests were made by EPA personnel on the gas scrubbing systems of two totally enclosed furnaces operating in Europe. All of these tests are described in more detail in Appendix A. The alphabetical designations of the tests follow chronological order; i.e., the first test, made on May 18-19, 1971, is designated Furnace A, and the last test, made on August 23-25, 1972, is designated Furnace L. Measurements were made of particulate mass emission rates, sulfur oxide content, carbon monoxide content, and particle sizes. Collected samples were also analyzed with either the atomic absorption method or the optical emission spectrograph. Particle size and chemical analysis are covered in more detail in Appendices D and E.

All EPA test data for particulate shown in this section of the report are based on that portion collected in the front half (probe, cyclone and filter) of the EPA sampling train. For results based on collection in the total sampling train, refer to Tables A-2 through A-5 in Appendix A.

The initial two tests in the sampling program were made on uncontrolled furnaces A and B. Furnace A was producing ferrochrome-silicon. Furnace B was a chrome ore/lime melt furnace and was the only open-arc furnace tested. The average concentration of particulate from the uncontrolled FeCrSi furnace was 0.21 gr/scf, and the mass emission rate was 29 lb/mw-hr. The average gas flowrate from this uncontrolled system was 159,150 scfm dry. The average concentration of particulate from the uncontrolled chrome ore/lime melt furnace was 0.16 gr/scf, and the mass emission rate was 6 lb/mw-hr. The average gas flowrate from this uncontrolled system was 41,200 scfm dry.

Furnace C, a large, open, hooded furnace producing 2 percent carbon-grade silicomanganese, was controlled by two flooded-disc scrubbers installed in parallel and normally operated at 57 inches water pressure drop. Tests were conducted with the scrubbers adjusted to operate at 57, 47, and 37 inches $H_2O$ pressure drop. For 57 inches $H_2O$ pressure drop, the average outlet concentration and mass emission rate were 0.01 gr/scf and 0.33 lb/mw-hr, respectively, with an average dry gas flowrate of 115,000 scfm. For 47 inches $H_2O$ pressure drop, the average outlet concentration and mass emission rate were 0.015 gr/scf and 0.54 lb/mw-hr, respectively, at an average dry gas flowrate of 118,000 scfm. Particulate removal efficiency decreased very little when the scrubber was operated at 47 inches $H_2O$ pressure drop, possibly because inlet concentrations to the scrubber were higher at this pressure drop than they were at 57 inches $H_2O$ pressure drop. Scrubber performance differed noticeably, however, when the scrubber was operated at 37 inches $H_2O$ pressure drop. At this setting, the average outlet concentration and mass emission rate were 0.044 gr/scf and 1.45 lb/mw-hr, respectively, at an average dry gas volume flowrate of 110,000 scfm.

Furnace D, a large, open, hooded FeCrSi furnace, used an open, pressure-type baghouse for emission control. This type of baghouse is commonly used in the ferroalloy industry. The furnace tapping station was also vented to this baghouse. Measurements of the average concentration and mass emission rate at the baghouse outlet showed 0.003 gr/scf (including dilution air) and 0.42 lb/mw-hr, respectively. The gas flowrate into the baghouse was 178,000 scfm (dry) and, after dilution at the baghouse, the outlet flowrate was 383,000 scfm (dry).

Emissions from Furnace E, called the "largest U.S. ferrochrome furnace,"[21] were controlled by an electrostatic precipitator. The tapping station was also controlled by this precipitator. A 120-foot conditioning tower preceded the precipitator. The open, hooded furnace could be almost completely enclosed with sectional, vertically sliding doors. The average concentration and mass emission rate of particulates from the precipitator were 0.016 gr/scf and 0.64 lb/mw-hr, respectively. The measured gas flowrates at the precipitator stack outlet averaged 156,000 scfm (dry).

Furnace F produced silicon metal. Silicon metal furnaces are the most difficult and costly to control because the process generates large volumes of hot gases heavily laden with extremely fine silica fumes. Furnace F had a high canopy hood and was controlled by the only type of control system used on silicon furnaces - a baghouse. Tests averaged 391,000 scfm (dry) exhaust gases treated by three parallel-installed baghouses. After this amount of gas passed through the cloth filter bags, dilution air increased the baghouse outlet volume to 610,750 scfm. Total filter area was 344,000 square feet. These baghouses are the typical open, pressure type with a roof monitor. Average outlet particulate concentration (including dilution air entering at the baghouse) was 0.003 gr/scf (dry) and the average mass emission rate was 0.94 lb/mw-hr.

Furnace G was a small open furnace producing silicomanganese, well-enclosed and equipped with an Aeronetics scrubbing system. The hot, fume-laden gases were first ducted to a heat exchanger where heat was transferred to a high-pressure water stream. This water stream was then used in a two-phase (steam/water mist) jet nozzle located downstream of the heat exchanger.

This jet nozzle not only cleaned the dirty gases but also pumped the exhaust gases through the air pollution control system, precluding the need for exhaust fans. Another exhaust system vented the tapping station and tapping fumes to the top part of the furnace hooding, where it helped to supply combustion air for burning the carbon monoxide furnace offgas to carbon dioxide. Gas flowrate from the scrubber was 15,500 scfm (dry) at an average particulate concentration amd mass emission rate of 0.08 gr/scf and 1.48 lb/mw-hr, respectively.

Furnace H was a very large semi-enclosed furnace producing 50 percent FeSi. The control system serving this furnace consisted of two parallel-installed Chemico venturi scrubbers operating at 80 to 85 inches $H_2O$ pressure drop. The cleaned 7,000 scfm (dry) gases with high carbon monoxide content were flared at roof level. Particulate concentration before flaring was 0.06 gr/scf (dry) and mass emission rate from the scrubber exhaust was 0.08 lb/mw-hr. The measured mix seal losses from Furnace H varied from 136 to 569 lb/hr (3 to 13.5 lb/mw-hr).

Furnace J was a semi-enclosed furnace producing calcium carbide. This furnace had hollow electrodes through which smaller size lime and coke were fed into the furnace. The larger materials were charged through openings around the electrodes. This method of charging raw materials reportedly reduces the dust load going to the scrubber. Furnace emissions were controlled by a Buffalo Forge rotary scrubber. Average exhaust gas rate from the scrubber was 1,585 scfm (dry) at an average particulate concentration and mass emission rate of 0.03 gr/scf (dry) and 0.02 lb/mw-hr, respectively. The measured loss from mix seals on Furnace J varied from 44 to 50 lb/hr (1.8 to 2.2 lb/mw-hr).

Furnace K located in Norway was a totally enclosed furnace with fixed electrode seals. The furnace was producing FeMn when tested by EPA. Emissions from this furnace were controlled by two identical Warkaus scrubber systems installed in parallel. Each system consisted of a three-stage venturi scrubber. No exhaust fan was necessary because aspiration of gases was provided by water injection at the venturi. Tests were made when both scrubber systems were in operation and when only one scrubber system was in operation. Average exhaust gas rates were 5,559 scfm (dry) with both scrubber systems operating and 5,322 scfm (dry) with only one scrubber system operating. The average concentration and mass emission rate of particulates in the cleaned gas while both scrubber systems were operating were 0.013 gr/scf and 0.024 lb/mw-hr, respectively. With only one scrubber system in operation, the average outlet emission was 0.018 gr/scf (dry), which is equivalent to 0.031 lb/mw-hr. Infrequent puffs of fumes escaping from the electrode fixed seals were estimated to be less than 10 percent opacity.

Furnace L located in Norway was a 27-mw totally enclosed furnace with electrode seals. The furnace was producing 1 percent carbon-grade silicomanganese when tested. Emissions from this furnace were controlled by a system consisting of two venturi scrubbers operating in series. The first low-pressure venturi (2 inches $H_2O$ pressure drop) acted to condition the gas stream before it entered the high-pressure venturi (50 inches $H_2O$ pressure drop). The average exhaust flowrate was 2,417 scfm (dry) and the average emission was 0.01 gr/scf (dry), which is equivalent to 0.01 lb/mw-hr. The very small volumes of gases escaping from the electrode fixed seals were estimated to be less than 10 percent opacity.

Table VI-13 shows production data relating to the EPA tests. The first seven furnaces shown (A through G) are open and are equipped with high or low canopy hoods. The last four (H through L) have covers. All furnaces were operating at or near rated capacity. A continuous recording chart provided the furnace's electrical power input in megawatts; the average megawatt figures are shown for the test periods. The last two columns in this table, tons product per hour and tons charge per hour, were derived from data in the preceding three columns. For example, the 1.35 tons/hr of FeCrSi product for Furnace A was obtained by dividing the average operating load (10 megawatts) by the electrical energy production factor (7.4 mw-hr per ton of alloy). The 4.6 tons/hr of charge material was obtained by multiplying the product (1.35 tons/hr) by the charge-to-product ratio (3.4 tons/ton alloy).

Table VI-14 summarizes EPA particulate test results. These test data correspond in time to the furnace production rates shown in Table VI-13. The first two furnaces (A and B) were uncontrolled. The last two furnaces tested (K and L) were the best controlled. Overall control efficiencies shown in this table include losses from the furnace plus those from the tapping station unless otherwise specified. All scrubber systems serving the four covered furnaces had an estimated scrubber collection efficiency of over 99 percent based upon the use of uncontrolled emission factors for inlet loadings. Because of heavy fume losses from the mix seals, estimated overall efficiencies (excluding tapping emissions) from Furnaces H and J were lower, 89 and 96 percent respectively. For open furnaces equipped with hoods, the highest overall particulate collection efficiency (excluding tapping emissions obtained was 99.1 percent. Overall particulate collection efficiencies for furnaces with open hoods are based on the losses from the control device plus

Table VI-13. SUMMARY OF PRODUCTION DATA DURING EPA TESTS

| Furnace designation | Type of furnace |  | Product | Average operating load during test, mw | Average Production factors |  | Product, ton/hr[a] | Charge ton/hr[a] |
|---|---|---|---|---|---|---|---|---|
|  | Open | Covered |  |  | Charge ratio, tons/ton alloy (average) | Electrical energy, mw-hr per ton alloy (average) |  |  |
| A | X |  | FeCrSi | 10 | 3.4 | 7.4 | 1.35 | 4.6 |
| B | X |  | Cr ore/ lime melt | 9 | 1.2 | 1.2 | 7.5 | 9.0 |
| C | X |  | SiMn | 27 | 3.1 | 4.4 | 6.15 | 19.0 |
| D | X |  | FeCrSi | 21 | 3.4 | 7.4 | 2.85 | 9.7 |
| E | X |  | FeCr (HC) | 33 | 4.0 | 4.2 | 7.85 | 31.5 |
| F | X |  | Si | 17 | 4.9 | 14.0 | 1.21 | 5.9 |
| G | X |  | SiMn | 7.2 | 3.1 | 4.4 | 1.63 | 5.1 |
| H |  | X[b] | 50% FeSi | 44 | 2.5 | 5.0 | 8.80 | 22.0 |
| J |  | X[b] | $CaC_2$ | 23 | 1.6 | 2.6 | 8.85 | 14.2 |
| K |  | X[c] | FeMn | 27 | 3.0 | 2.4 | 11.25 | 33.8 |
| L |  | X[c] | SiMn | 23 | 3.1 | 4.4 | 5.23 | 16.2 |

[a] Tons product and tons charge per hour based on average production factors.

[b] Covered furnace with mix seals.

[c] Totally enclosed furnace.

Table VI-14. SUMMARY OF EPA FERROALLOY FURNACE EMISSION TESTS

| Furnace designation | Type of furnace | | Type of control | Product | Volume of gas to control system, scfm(dry) | Inlet particulate loading[a] | | Outlet particulate emissions[a] | | | | | | Efficiencies | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Open | Covered | | | | gr/scf | lb/Mw-hr | lb/Mw-hr | gr/scf | lb/hr | lb/ton product | lb/ton charge | Controlled-stack visible emissions, % opacity during test | Control equipment efficiency only, % | Estimated overall collecting efficiency, % |
| A | X | | None | FeCrSi | 159,150 | 0.21 | 29 | -- | -- | -- | -- | -- | 80-100[b] | 0 | 0 |
| B | X | | None | Cr ore/ lime melt | 41,200 | 0.16 | 6 | -- | -- | -- | -- | -- | 80-100[b] | 0 | 0 |
| C | X | | Venturi | SiMn | 115,000 | 1.2 | 40 | 0.33 | 0.01 | 8.9 | 1.45 | 0.47 | 0 | 99.2 | 99.1[c] |
| D | X | | Baghouse | FeCrSi | 178,000[d] | 0.35 | 25 | 0.42 | 0.003 | 8.8 | 3.01 | 0.91 | 0 | 98.3 | 98.1 |
| E | X | | Precipitator | HC, FeCr | 156,000 | 0.93 | 39 | 0.64 | 0.016 | 21.0 | 2.70 | 0.67 | 0-10 | 98.4 | 98.0 |
| F | X | | Baghouse | Si | 391,000[d] | 0.70 | 144 | 0.94 | 0.003[e] | 16.3 | 13.50 | 2.76 | 0 | 99.1 | 96.0[c] |
| G | X | | Venturi | SiMn | 15,500 | 1.7 | 28 | 1.48 | 0.08[f] | 10.6 | 6.50 | 2.08 | 0[g] | 94.5 | 94.0 |
| H | | X | Venturi | 50% FeSi | 7,613[h] | 60[i] | 89[i] | 0.08 | 0.06[j] | 3.7 | 0.42 | 0.17 | 0[j] | 99.9[i] | 91.0[c] |
| J | | X | Scrubber[k] | $CaC_2$ | 1,585[h] | 50 | 29 | 0.02 | 0.03 | 3.4 | 0.04 | 0.03 | 0 | 99.9[i] | 94.0[c] |
| K | | X | Venturi | HC, FeMn | 5,322[h] | 37[i] | 62[i] | 0.024 | 0.013 | 0.6 | 0.06 | 0.02 | 0 | 99.9[i] | > 99.1[c] |
| L | | X | Venturi | SiMn | 2,417[h] | 56[i] | 50[i] | 0.01 | 0.01 | 0.2 | 0.10 | 0.03 | 0 | 99.9[i] | > 99.1[c] |

[a] Based on front half of EPA sampling train; collected at control equipment inlet and outlet.

[b] Uncontrolled exhaust system.

[c] Does not include tapping losses.

[d] Does not include dilution air into baghouse.

[e] Includes dilution air into baghouse.

[f] Tight open hood (Aeronetics scrubber system).

[g] Long prevailing water vapor plume from scrubber; by time plume disappeared, plume had been diluted and no visible emission was noted.

[h] Collected gases from under the furnace cover.

[i] No inlet tests were made. Figures are based on production and emission factors.

[j] This concentration is before flare. Without flaring, visible emissions are 20-30%; no emissions are visible when gas is flared.

[k] Buffalo Forge scrubber.

the estimated losses escaping the hood.

Efficiencies of control devices cannot be used very well to compare losses from furnace to furnace because of the differences in furnace sizes. The most equitable comparison is based on the amount of loss related to furnace energy input. Using pounds per megawatt-hour as an emission rate unit, the lowest emission rates from the gas cleaning system were those from the scrubbers serving the four covered furnaces. For covered furnaces, the rates ranged from 0.01 lb/mw-hr for a venturi serving a SiMn furnace to 0.08 lb/mw-hr for a venturi serving a 50 percent FeSi furnace. For open furnaces, the emission rates from the gas cleaning system ranged from 0.33 lb/mw-hr for a venturi serving a large SiMn furnace to 1.48 lb/mw-hr for a venturi serving a small SiMn furnace. The emissions from the two baghouse systems tested on open furnaces were 0.42 lb/mw-hr for FeCrSi and 0.94 lb/mw-hr for silicon.

Fugitive fumes escaping from the mix seals on Furnaces H and J were measured. (These losses are not shown in Table VI-14.) The measured mix seal losses from Furnace H (50 percent FeSi) varied from 136 to 569 lb/hr (3 to 13.5 lb/mw-hr). The measured loss from the mix seals on Furnace J (calcium carbide) varied from 44 to 50 lb/hr (1.8 to 2.2 lb/mw-hr). These measured losses from the mix seals were somewhat higher than the ranges reported in questionnaire data, particularly for the 50 percent FeSi furnace (see Table VI-6). During the test, the furnace did not appear to operate smoothly at all times, and this may have resulted in heavier-than-normal emissions.

Uncontrolled tapping losses were measured from Furnaces C, H and J. Losses from Furnace J producing $CaC_2$ (continuous tapping) varied from 45 to 54 lb/hr. Losses from Furnace H producing 50 percent FeSi varied from 18 to 30 pounds per tapping period (12 to 17 minutes). Losses from Furnace C producing SiMn varied from 17 to 59 pounds per tapping period (28 to 32 minutes). On Furnaces D, E, and G, the tapping stations were served by the primary air pollution control systems.

Except for periods when there were visible emissions of approximately 10 percent opacity from the electrostatic precipitator serving Furnace E, no emissions were visible from any of the control systems tested under normal operating conditions. The uncontrolled fume emissions from the mix seals of furnace H caused visible stack emissions estimated in the range of 20 to 60 percent opacity, but during short periods of rough furnace operation the visible emissions were as high as 100 percent. These readings were taken on a random basis. Visible emissions from the electrode seals on the two furnaces in Norway were normally less than 10 percent opacity at the furnace area; at times there were no visible emissions. Visible emissions from all furnaces without tap fume control varied during the tapping cycle from 10 to 100 percent.

Temperatures of furnace gas entering the air pollution control devices varied depending on furnace hooding and the extent of precooling. The temperature of the gas stream entering a conditioning tower preceding an electrostatic precipitator (Furnace E) varied from 429 to 492°F during the EPA tests. Temperature of the gas stream entering a venturi scrubber on an open silicomanganese furnace (Furnace C) varied from 541 to 645°F. Gas temperature from a closely hooded furnace producing silicomanganese.

(Furnace G) was purposefully high to recover heat. Temperature in the furnace outlet exhaust duct was between 1100 and 1133°F, but after passing through a heat exchanger and before entering a two-phase jet scrubber, it decreased to 320 to 358°F. Temperatures of gas streams entering baghouses on Furnaces D and F ranged from 306 to 330°F, and the gas streams were cooled to these temperatures by dilution air at the hood and by radiant cooling while the gas passed through several hundred feet of ducting.

Five ASME samples were obtained using the ASME power test code method and compared with results obtained by the EPA test method. All samples were collected from the hot, heavily dust-laden gas stream from the furnace. The two methods compared favorably for three tests, but no correlation could be determined for the other two tests (see Appendix A). Only the front half (probe and cyclone) particulate catch in the EPA train was compared with the ASME samples.

Emissions from the nine furnaces tested in the United States compare within normal ranges with the information provided by the questionnaires for similar products (see Table VI-15). Emissions from eight of the furnaces tested were lower than the average of the questionnaire information; no questionnaire data were available on the calcium carbide furnace for comparison. The one product that differed markedly was FeCrSi. Test results obtained by EPA were much lower than those reported on the questionnaires. The fact that fines were screened from the FeCrSi charge material for the furnaces tested by EPA may account for the difference.

b. Particle Size Determinations - Determinations of particle size distribution of uncontrolled and controlled furnace fume emissions were made at several ferroalloy plants while emission tests were conducted.

Table VI-15. COMPARISON OF EPA TEST RESULTS AND QUESTIONNAIRE DATA

(lb/ton product)

| Furnace | Product | Control system | Type of furnace | EPA test results[a] |  | Questionnaire data |  |
|---|---|---|---|---|---|---|---|
|  |  |  |  | Inlet | Outlet | Inlet | Outlet |
| A | Ferrochrome-silicon | None | Open | 231[b] | - | 831[b] | 14.1[c] |
| B | Cr ore/lime melt | None | Open | 7.8[b] | - | 11[b] | - |
| C | Silicomanganese | Scrubber | Open | 178 | 1.63 | 219 | 3.3 |
| D | Ferrochrome-silicon | Baghouse | Open | 223 | 7.67 | 831 | NR[d] |
| E | HC ferrochrome | ESP | Open | 138 | 2.53 | 335 | e |
| F | Silicon metal | Baghouse | Open | 1945 | 14.7 | 1200[2] | NR |
| G | Silicomanganese | Scrubber | Open | 140 | 7.05 | 219 | 3.3 |
| H | 50% Ferrosilicon | Venturi scrubber | Semi-enclosed | No Test | 0.42 | 446 | 0.65 |
|  |  | Canopy hood for fugitive dust | Semi-enclosed | - | 17.6[b] | - | 23.7[b] |
| J | Calcium carbide | Centrifugal scrubber | Semi-enclosed | 76.6[f] | 0.06 | - | 0.55 |
|  |  | Canopy hood for fugitive dust | Semi-enclosed | - | 7.02[b] | - | 9.0[b] |
| K | HC Ferromanganese | Venturi scrubbers | Totally enclosed | No test | 0.07 | - | NR |
| L | Silicomanganese | Venturi scrubbers | Totally enclosed | No test | 0.10 | - | NR |

[a] Based on front half of EPA sampling train.

[b] Uncontrolled exhaust system.

[c] Only data were for a scrubber.

[d] None reported.

[e] No data - ESP installed after questionnaire survey.

[f] Test based on samples collected of suspended solids in scrubber water outlet.

[g] Questionnaire data not conclusive. Number presented is an estimate of the ferroalloy industry.

Samples for evaluation of particle size distribution were collected initially with the Andersen Stack Sampler, but most of the data were based on the samples collected by the Brink Cascade Impactor. Because of the heavy and fluctuating dust load from the furnace, sampling time at the inlet of the control devices was short and may not have been representative of an average hourly sample. Initially, the sampler was modified with a dilution system to obtain longer sampling times at the inlets, but high temperatures caused equipment failure. More representative particle size analyses were obtained at the control equipment outlets because longer sampling times were possible. Table VI-16 shows the furnaces, products, control equipment, and number of samples obtained by each sampler.

Very little published information exists on the size distribution of particulate matter from ferroalloy furnaces. Person and Silverman state that most particles are less than 0.5 micron diameter.[17,18] EPA verified this number by use of the cascade impactor.

Cumulative weight percentages for each stage of the cascade impactor were arithmetically averaged, and the combined size distributions are shown in Table VI-17. From a furnace producing ferrochrome (see Figure A-6, Appendix A), 50 percent of the outlet fume weight is composed of particles smaller than 1.68 micron diameter. Fumes from two furnaces producing FeCrSi contain somewhat smaller particles, with 50 percent of the weight normally composed of particles smaller than 0.9 micron.

Table VI-16. PARTICLE SIZE SAMPLES

| Furnace designation | Product | Control equipment | Number of samples | | | |
|---|---|---|---|---|---|---|
| | | | Brink | | Andersen | |
| | | | Inlet | Outlet | Inlet | Outlet |
| A | FeCrSi | None | 3 | | 6 | |
| B | Cr ore/lime melt | None | | | 1 | |
| C | SiMn | Scrubber | 8 | 10 | | |
| | SiMn[a] | None | 4 | | | |
| D | FeCrSi | Baghouse | 9 | 8 | | |
| E | FeCr (HC) | Precipitator | 6 | 6 | | |
| G | SiMn | Scrubber | | | | |

[a] Tapping fumes.

Table VI-17. PARTICLE-SIZE DATA FROM EPA TESTS[23]

| Furnace designation | Furnace | Product | Collection device | Sampling point | No. of tests | Mass median diameter, microns | Standard geometric deviation, microns |
|---|---|---|---|---|---|---|---|
| A | Open | FeCrSi | None | Furnace outlet | 3 | 0.66 | 1.90 |
| C | Open | SiMn | High-energy scrubber | Scrubber outlet | 8 | 0.43 | 2.74 |
| C | Open | SiMn | High-energy scrubber | Inlet | 6 | 1.16 | 2.16 |
| C | Open | SiMn | None at taphole | Taphole fumes | 4 | 1.49 | 3.91 |
| D | Open | FeCrSi | Baghouse | Baghouse outlet | 7 | 0.93 | 3.38 |
| D | Open | FeCrSi | Baghouse | Inlet | 9 | 0.98 | 5.00 |
| E | Open | HC FeCr | ESP | ESP outlet | 5 | 1.51 | 4.04 |
| E | Open | HC FeCr | ESP | ESP inlet | 6 | 1.72 | 4.72 |

c. Chemical Analysis - During the test program, EPA collected several samples for chemical analysis to determine percent of sulfur dioxide in the gas stream and percent metals content of the collected dust. In addition, metals analysis was performed on two manganese ore samples, two chrome ore samples, and a sample of ferromanganese slag used as part of the charge to a SiMn furnace. No significant sulfur dioxide concentrations were found in the exhaust gas for the first five furnaces tested by EPA (A through E). The $SO_2$ loss from furnaces equipped with control devices did not exceed 7 pounds per hour. For Furnace A (FeCrSi), the $SO_2$ concentration ranged from 14 to 17 ppm. No $SO_2$ was found in the gas from the chrome ore/lime melt furnace. The $SO_2$ content in the gas from Furnace C (SiMn) was less than 1 ppm. The $SO_2$ in the gas from a FeCrSi furnace (Furnace D) ranged from 8 to 9 ppm and was quite similar to Furnace A, which also produced FeCrSi. The $SO_2$ concentrations in the gas from an HC FeCr furnace ranged from 1 to 8 ppm. Because concentrations in these five furnaces were low, no additional $SO_2$ analyses were made. The $SO_2$ samples were analyzed with the modified Shell Development method.

Particulates collected by the EPA sampling train were analyzed for metals. The analytical results for particulate collected on the glass fiber filters are presented in Table VI-18. This table shows that the particulate specimens from furnaces producing different products are distinctly different in chemical composition. Gas samples analyzed were collected at both the inlets and outlets of the control devices. Samples collected at scrubber outlets differed markedly in sodium and potassium content. Samples from scrubbers using recycled water were high in potassium and sodium.

Table VI-18. CHEMICAL ANALYSIS OF SAMPLES
(percent)

| Product | FeCrSi | FeCrSi | | | SiMn | | | | | SiMn | Cr ore/lime melt | HC FeCr | | FeMn | 50% FeSi | Si |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Furnace designation | A | D | | | C | | | | | L | B | E | | K | H | F |
| Furnace type | Open | Open | | | Open | | | | | Semi-enclosed | Open | Open | | Semi-enclosed | Semi-enclosed | Open |
| Sample/sample point | Furnace | Baghouse inlet | Baghouse outlet | Chrome ore | Scrubber stack outlet | Scrubber water outlet | Tapping | Mn ore charge[a] | FeMn slag charge[a] | Scrubber stack outlet | Furnace | ESP conditioning tower inlet | ESP collected dust | Scrubber stack outlet | Scrubber stack outlet | Baghouse outlet |
| Analytical method | b | b | b | c | b | c | b | c | c | c | b | b | c | c | c | c |
| Chemical constituent | | | | | | | | | | | | | | | | |
| $SiO_2$ | 73.7 | 76.4 | d | 8.6 | d | 0.095 | d | 14.0 | 14.0 | d | 10.3 | 15.0 | 17.2 | -- | d | d |
| Mn | 0.07 | 0.05 | 0.1 | 0.1 | 14.3 | 0.07 | 21.8 | d | d | 1.0 | 0.11 | 0.18 | 0.2 | 3.47 | -- | 0.002 |
| Cr | 1.41 | 0.44 | < 0.4 | 30.0 | 0.07 | e | 0.1 | 0.01 | 0.115 | < 0.013 | 15.3 | 14.0 | 4.0 | < 0.008 | -- | 0.002 |
| Fe | 0.34 | 0.60 | 1.0 | 5.0 | 0.5 | 0.004 | 1.0 | 3.5 | 9.0 | < 0.064 | 5.2 | 3.66 | 1.0 | 0.21 | -- | 0.016 |
| Al | 0.10 | 0.37 | 8.0 | 7.0 | 0.7 | 0.01 | 0.7 | 3.5 | 4.0 | -- | 0.55 | 6.33 | 5.0 | -- | -- | 0.10 |
| Ca | -- | 0.43 | 4.0 | 0.35 | 0.6 | 0.016 | 0.4 | 0.3 | 0.2 | < 0.33 | 10.7 | 0.27 | 0.3 | 5.08 | -- | 0.06 |
| Mg | 7.70 | 5.40 | 0.6 | 10.0 | 1.6 | 0.02 | 0.6 | 0.25 | 0.25 | < 0.33 | 7.5 | 8.9 | 15.0 | 2.08 | 4.0 | 0.03 |
| Na | -- | 0.23 | 12.7 | 0.01 | 34.5 | 0.055 | 0.05 | 0.35 | 0.3 | 1.64 | -- | 4.22 | 15.0 | 1.04 | 40.0 | 0.03 |
| Zn | 0.69 | 0.35 | 0.6 | < 0.02 | 0.7 | e | 0.3 | < 0.02 | < 0.01 | < 0.044 | 2.8 | 0.93 | 0.5 | 1.39 | 0.4 | 0.003 |
| K | -- | 0.25 | 0.9 | < 0.05 | 23.4 | 0.1 | 6.0 | 2.0 | 1.5 | 2.30 | -- | 5.95 | 10.0 | 1.46 | 74.0 | 0.17 |
| Pb | < 0.001 | -- | -- | < 0.01 | -- | f | -- | < 0.01 | < 0.01 | 0.002 | 0.006 | -- | 0.1 | 0.113 | -- | 0.001 |
| Ba | -- | < 0.4 | < 0.4 | -- | -- | -- | -- | -- | -- | -- | -- | 0.11 | -- | < 0.03 | 2.0 | -- |
| Ti | -- | < 0.8 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Hg | < 0.05 | -- | -- | g | -- | g | -- | g | g | -- | < 0.05 | -- | g | -- | -- | -- |
| Cd | < 0.005 | -- | -- | < 0.01 | -- | g | -- | < 0.01 | < 0.01 | < 0.004 | 0.002 | -- | 0.01 | 0.19 | -- | f |
| Be | < 0.001 | -- | -- | e | -- | g | -- | f | < 0.001 | f | < 0.001 | -- | e | g | -- | g |
| V | < 0.03 | -- | -- | 0.05 | -- | g | -- | 0.03 | 0.06 | < 0.013 | < 0.03 | -- | 0.006 | < 0.011 | -- | f |
| As | -- | -- | -- | < 0.02 | e | -- | -- | < 0.02 | -- | < 0.044 | -- | -- | 0.02 | < 0.027 | -- | < 0.002 |

[a] Average of two samples.

[b] Atomic absorption method.

[c] Optical emission spectrography method.

[d] Not determined. Major constituent over 25%.

[e] Less than 2 ppm.

[f] Less than 5 ppm.

[g] Less than 1 ppm.

By comparison, the concentrations of sodium and potassium in samples obtained from scrubber outlets for Furnaces K and L, which use only fresh water, were very low. Sodium and potassium compounds are highly soluble in water and are thus difficult to remove by water treatment. Hence, the concentrations of soluble compounds in the water recycled to the scrubber will build up and may be stripped out when the scrubber water contacts the high-temperature gases; emissions will increase accordingly. Sodium fumes are extremely fine in the solid state and are difficult to remove, as demonstrated by the samples collected from the inlets and outlets of a baghouse serving a FeCrSi furnace. The sodium in the outlet was found to be 12.7 percent, but the inlet sample contained only 0.23 percent sodium, indicating the fractional collection efficiency was very low for sodium fumes.

Residue samples from untreated scrubber water were obtained from the high-energy scrubber at Furnace C (SiMn). The metals contained in higher percentages in the water sample appeared to match the metals contained in higher percentages in the scrubber outlet sample.

### 6. Data from Other Sources

a. Quantities of Emissions from European Furnaces - All major types of control systems are used in Europe to control emissions.

A plant located in Germany prefers to use electrostatic precipitators. One of their newer units se[illegible] ferrochrome silicon furnace with a reported dust loss ranging from 2.[illegible]/mw-hr.[19]

Operation of a high-energy venturi for cleaning the collected gas on a closed 45 percent ferrosilicon furnace located in the USSR results in a reported dust concentration in the cleaned gas of 0.001 to 0.009 gr/scf and a mass emission rate varying from 0.015 to 0.10 lb/hr. The reported flow rate varies from 1000 to 1300 scfm. The total system's water flowrate is 150 to 225 gallons per minute (gpm) with a scrubber pressure drop of 70 to 95 inches water.[24] The furnace load and sampling method are not specified. It is assumed that the furnace is not totally enclosed because of the marked decrease in gas volume with increase in undercover pressure.

An electrostatic precipitator used on an open 75 percent ferrosilicon furnace located in Switzerland reportedly cleans the exhaust gas to 0.035 to 0.066 gr/scf corresponding to 2.5 to 4.8 lb/mw-hr. The gases are prescrubbed and conditioned by passing through a 15-centimeter wetted layer of glass balls.[36] Higher emissions occur 3 minutes every hour, when the plates are washed.

Reaction furnace gases from a totally enclosed calcium carbide furnace located in Germany are cleaned and used as synthesis gas. The collected gases are cleaned with ceramic cylinder filters called "filter candles." The furnace gas is cooled to 932°F before entering the filters. The high-temperature gases prevent formation of condensate on the filter. Condensates in the gas stream are removed downstream of the collector by water-cooled condensers. Dust deposits are alternately removed from the filters in the compartments of the collector by heating part of the cleaned gas stream and passing it through the filters in a reverse direction to the normal flow. The system is designed to reduce the dust concentration in the cleaned gas to less than 0.004 gr/scf.[25]

An electrostatic precipitator serving an open silicon furnace in Norway has encountered corrosion problems caused by water condensate and small amounts of $SO_2$. The ESP unit is preceded by a large treatment chamber that cools the gases with water and adds gaseous ammonia. It was verbally reported that tests have shown this ESP system to be 97 percent effective when the inlet gas temperature is decreased to 158°F and 18 pounds per hour of anhydrous ammonia are added.[26]

Several ferroalloy plants in Europe use baghouses on open furnaces but no baghouses are known to be used on covered furnaces in Europe. Test results for baghouse outlet loadings, if available, have not been reported.

b. Reported Quantities of Emissions from Japanese Furnaces[34] - The Japanese ferroalloy industry in recent years has built several totally enclosed furnaces and achieved an excellent level of air pollution control from these units as well as other areas within the plant. In general, this control has been accomplished by a combination of furnace design, seals at the electrodes, furnace-feed pretreatment, control of emissions from pretreatment processing equipment, control of furnace tap fumes, and control of emissions from product crushing and sizing equipment.

Table VI-19 shows reported emission levels from a select group of well-controlled Japanese furnaces, most of which are totally enclosed. In most of the installations, the cleaned furnace gas is used as fuel for raw material dryers and plant boilers, or it is sold to neighboring chemical plants. The gas volume for furnace 4 is not listed, but that furnace is closely hooded and allows only enough induced air to combust the reaction

Table VI-19. REPORTED EMISSION DATA AND RELATED INFORMATION FOR WELL-CONTROLLED JAPANESE SUBMERGED-ARC FURNACES

| Furnace | Type furnace | Electrode seals | Product | Furnace size, mw | Feed pre-treatment | Air pollution control equipment | Volume of gas, scfmx1000 | Reported measured emissions |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |  | gr/scf | lb/mw/hr |
| 1 | Totally enclosed | Yes | 75% FeSi | 12 | None | Venturi | 1.3 | 0.035 | 0.03 |
| 2 | Totally enclosed | Yes | HC Fe | 32 | a | Venturi-ESP | 3.7 | 0.002 | 0.003 |
| 3 | Totally enclosed | Yes | HC FeCr | 17 | b | Baghouse | 2.5 | -- | -- |
| 4 | Open | No | FeNi | 15 | c | Baghouse | -- | -- | -- |
| 5 | Totally enclosed | Yes | FeCrSi | 26 | d | Venturi | 3.1 | 0.010 | 0.01 |
| 6 | Totally enclosed | Yes | SiMn | 35 | a | Venturi & Theisen | 4.3 | -- | -- |
| 7 | Totally enclosed | Yes | HC FeMn | 25 | a | Venturi & Theisen | 4.3 | -- | -- |
| 8 | Open | No | 75% FeSi | 28 | None | Baghouse | 180.0 | <0.03 | <1.5 |
| 9 | Totally enclosed | Yes | 50% FeSi | 36 | e | Venturi-ESP | -- | 0.001 | 0.002 |
| 10 | Totally enclosed | Yes | 50% FeSi | 57 | e | Venturi-ESP | 7.4 | 0.001 | 0.002 |
| 11 | Totally enclosed | Yes | HC FeMn | 15 | None | Rotoclone | -- | -- | -- |
| 12 | Totally enclosed | Yes | SiMn | 32 | None | Venturi & Theisen | 2.9 | 0.002 | 0.002 |
| 13 | Totally enclosed | Yes | HC FeMn | 29 | None | Venturi & Theisen | 3.7 | 0.001 | 0.004 |
| 14 | Totally enclosed | Yes | SiMn | 32 | None | Venturi & Theisen | 2.9 | -- | -- |
| 15 | Open | Yes | HC FeCr | 20 | None | Baghouse | 66.5 | 0.02 | 0.57 |

[a] Cokes and ores dried and screened.

[b] Ores and coke dried, crushed, and pelletized. Pellets are then dried, pre-reduced, and charged hot (900°C) into furnace.

[c] Ores pre-reduced.

[d] Cokes crushed and dried. Ores crushed and screened.

[e] Ores and cokes sized, sintered, and pelletized; units use iron ore as a feed material in place of scrap steel.

gases coming from the furnace. Although furnace 15 has electrode seals, it is classified as an open furnace because the electrodes are sealed to an open canopy hood, which extends down to the top of the furnace and limits the amount of combustion.

In Japan the most commonly used air pollution control equipment consists of venturi scrubbers, pressurized fabric filters, electrostatic precipitators, Theisen centrifugal scrubbers or various combinations of these devices. Fabric filter collectors, in conjunction with furnace and/or ladle hooding, are used in some installations to control furnace tapping fumes. When observed by EPA personnel, the furnaces listed in Table VI-18 had no visible emissions. Reported emission rates were obtained by use of the Japan Industrial Standard test method. Concentrations of emissions to the atmosphere from air pollution control systems for cleaning the collected furnace gases varied from 0.001 to 0.035 gr/scf while mass emissions varied from 0.002 to 1.5 lb/mw-hr.

# VII. DESCRIPTION OF CONTROL SYSTEMS

For 40 years various types of particulate emission control systems have been used on a limited basis by the ferroalloy industry to reduce the high levels of suspended particulate matter often existing near plant sites and causing ambient air problems. During this time the industry has sought an economical means for controlling particulates and has tried systems using scrubbers, filters, and electrostatic precipitators. Over the years, four different control systems have been used by the industry:

1. Scrubbers serving open furnaces,
2. Cloth filters serving open furnaces,
3. Scrubbers serving covered furnaces, and
4. Electrostatic precipitators serving open furnaces.

## A. SCRUBBERS SERVING OPEN FURNACES

The most prevalent type of wet collector used for cleaning the large gas volumes from open furnaces is the high-energy venturi scrubber. Of the several designs of venturi scrubbers, the one now generally used in the United States is the flooded-disc scrubber (see Figure VII-1). The adjustable disc can be raised or lowered to decrease or increase scrubber efficiency. A two-phase jet scrubber system has also been developed and used to reduce emissions from several furnaces.

Because large quantities of submicron particulates are emitted from ferroalloy furnaces, venturi scrubbers require pressure drops of about

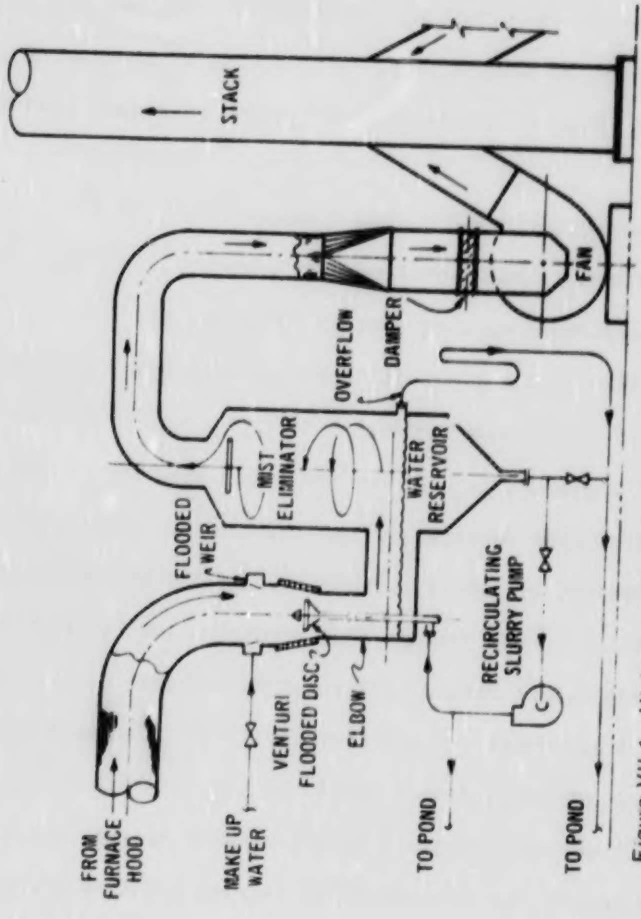

FROM FURNACE HOOD
MAKE UP WATER
VENTURI FLOODED DISC
ELBOW
TO POND
TO POND
FLOODED WEIR
RECIRCULATING SLURRY PUMP
MIST ELIMINATOR
WATER RESERVOIR
OVERFLOW
DAMPER
FAN
STACK

Figure VII-1. High energy fume scrubbing system for submerged-arc furnace.

60 inches water gauge to obtain a removal efficiency of 96 to 99 percent.

The venturi scrubber is capable of absorbing gas temperature peaks by evaporating more water. Multiple units may be required if water distribution across the throat is inadequate. Improved performance can be obtained by increasing either the scrubbing water or the gas velocities. One of the greatest advantages of scrubbers over other types of collectors is this operational flexibility.

However, scrubbers also have some disadvantages. Steam plumes are usually noticeable in the exhaust gases entering the atmosphere because the hot furnace gas evaporates large quantities of scrubber water and the moisture is often condensed in the cooler atmosphere. Large quantities of scrubber water are necessary, and to minimize water usage it may become necessary to recirculate dust-laden water to the cooling-spray zones of the scrubber system. When this happens, previously captured dust in the recycled water is released into the gas stream, and scrubber efficiency is thus reduced.[27] Another disadvantage of scrubbers is the potential transformation of an air pollution problem into a water pollution problem. The power required to operate these high-energy scrubbers is equivalent to about 10 percent of the total power supplied to the furnace.

Because most venturi scrubbers recirculate the scrubbing liquor, water usage is held to that exhausted in the gas stream plus that bled off with the collected solids. The scrubbing liquor containing the collected solids is clarified in thickeners or settling ponds.

A new type of dust-removal system uses waste heat from the furnace to provide the energy for gas scrubbing without the use of exhaust fans. This system is shown in Figure VII-2. At one plant, four such units have

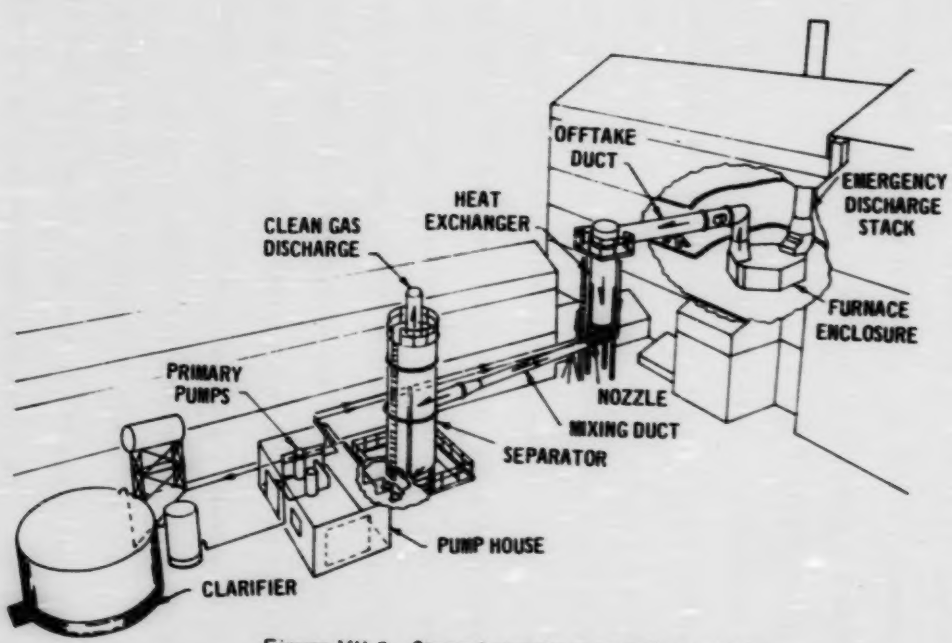

OFFTAKE DUCT
EMERGENCY DISCHARGE STACK
HEAT EXCHANGER
CLEAN GAS DISCHARGE
FURNACE ENCLOSURE
PRIMARY PUMPS
NOZZLE
MIXING DUCT
SEPARATOR
PUMP HOUSE
CLARIFIER

Figure VII-2. Steam-hot water scrubbing system.

recently been installed to serve four ferroalloy furnaces. In brief, the combusted reaction gases pass through a heat exchanger, a nozzle, and a separator before the cleaned gas is discharged to the atmosphere. To describe the process in more detail, heat from the reaction gases is transferred to the water in the heat exchanger, increasing the temperature of the water to 350 or 400 F and increasing water pressure to about 300 pounds per square inch (psi). As the heated water is expanded through the nozzle of the scrubber, partial flashing occurs, and the remaining liquid is atomized. Thus, a two-phase mixture of steam and small droplets leaves the nozzle at high velocity. At the same time, reaction gas from the furnace is aspirated by this high-velocity two-phase mixture, and in the subsequent mixing, the high-velocity water entrains the particulates that had been contained in the reaction gas. The mixture of steam, gas, and dust-laden water droplets then passes through a separator where the water and dust are separated from the gas-steam mixture. Cleaned gas leaves the separator through the stack and dirty water is discharged from the separator to a waste-water treatment system. Chemicals and other treatment are applied to settle solids and other contaminants from the water, and fluid waste is discharged to settling ponds. The water is then deionized, filtered, and returned to a pump for recycling to the heat exchanger. Makeup water is added to replace any losses.

## B. CLOTH FILTERS SERVING OPEN FURNACES

In a cloth filter system, dust and condensed fumes are retained on the "dirty gas" side of the filter, and cleaned gas passes through the filter to the "clean gas" side. Collected dust particles are then removed from the fabric by pneumatic or mechanical devices. Fabrics used are cotton, wool, nylon, Orlon$^{R}$, Dacron$^{R}$, Nomex$^{R}$, acetates, fiber-glass, etc. Synthetic fibers are either produced as a continuous filament, then spun and woven into yarn in the usual manner, or they are cut into short lengths or "staple," which may be spun, woven, or impacted into a felt. Woven fabrics are identified by thread count and by weight of fabric per unit area. Felts are identified in terms of thickness and weight per unit area.

The ability of the filter medium to pass clean air is stated as "permeability," which is the volume of clean air in cubic feet per minute that is passed through 1 square foot of the filter at a pressure differential of 0.5 inches water gauge. The amount of furnace gas that a fiber-glass cloth filter can handle without blinding is a maximum of about 2 actual cubic feet per minute (acfm) per square foot of filter area. This low air-to-cloth ratio can result in the use of thousands of bags so that baghouses serving ferroalloy furnaces require large areas. A baghouse also has many moving parts, because the bags must be flexed or shaken to discharge the dust. Conveying the collected dust from the baghouse hopper to a dust storage bin requires several enclosed screw conveyors and an enclosed elevator.

The baghouse in Figure VII-3 is typical of those used in the ferroalloy industry. The walkway access area around the bottom part of the compartment is shown as being solid, but these walkways are normally grated to allow outside cooling air to enter and mix with the hot filtered gases at approximately a 1-to-1 ratio. The resultant cooling effect within the

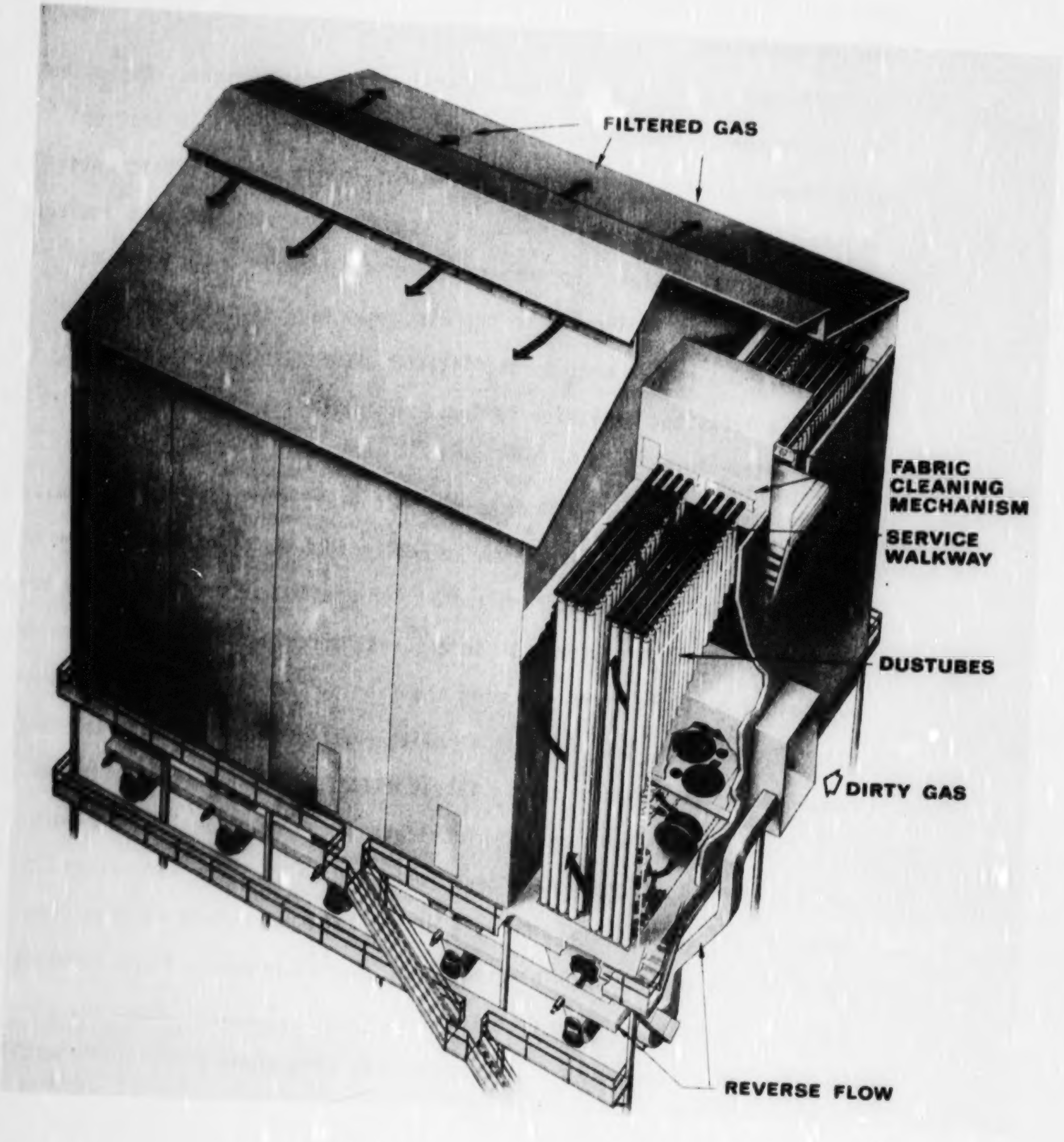

FILTERED GAS
FABRIC CLEANING MECHANISM
SERVICE WALKWAY
DUSTUBES
DIRTY GAS
REVERSE FLOW

Figure VII-3. Typical baghouse. (Courtesy of Wheelabrator-Frye, Inc.)

baghouse compartment makes it easier for personnel to replace bags during operation.

Unequal bag life necessitates frequent bag replacement. Baghouses in the ferroalloy industry are designed with compartments so that one compartment can be shut down for maintenance while other compartments continue to operate. Means for easy access to the bags are also included in the original design. In most cases, open, pressure-type baghouses are used; the fan is located on the dirty gas side of this kind of baghouse. Bag replacement is facilitated with this type of baghouse because a leaky bag is easier to locate when the gas flows from the inside of the filter bags.

Gas temperatures are limited to about 500°F for treated fiberglass. Gases from the furnace must often be cooled by heat transfer surfaces or by air dilution before entering the filter media. Figure VII-4 illustrates one type of cooling system. In some cases, arresters are used to prevent overheated particles from reaching the fabric. Cooling the gas by water spray is possible, but requires a reliable spray control system to prevent condensation of moisture on the fabric filters and subsequent blinding.

Cloth filters with air-to-cloth ratios ranging from 1.5 to 2 acfm per square foot of cloth have been installed on 12 large ferroalloy furnaces in recent years. Because of the high percentage of submicron particulates and the high electrostatic charge, pressure drops across the filters are high, ranging from 10 to 18 inches of water. However, the pressure drops for cloth filters are lower than those for venturi scrubbers

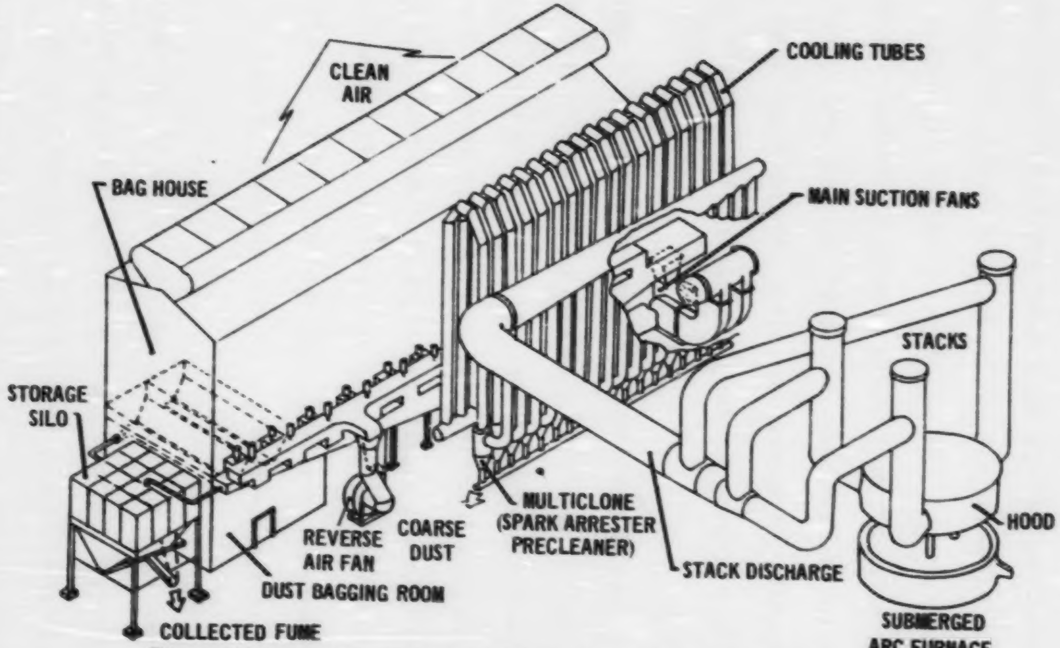

CLEAN AIR
COOLING TUBES
BAG HOUSE
MAIN SUCTION FANS
STACKS
STORAGE SILO
MULTICLONE (SPARK ARRESTER PRECLEANER)
HOOD
REVERSE AIR FAN
COARSE DUST
STACK DISCHARGE
DUST BAGGING ROOM
COLLECTED FUME
SUBMERGED ARC FURNACE

Figure VII-4. Baghouse system with cooling train for submerged-arc furnace.

with equivalent efficiencies and gas flows; consequently, the power required for the cloth filter exhaust system is less.

## C. SCRUBBERS SERVING COVERED FURNACES

A covered ferroalloy furnace has a water-cooled cover that seals the top of the furnace, including the electrodes, mix spouts, and access openings. This seal prevents the induction of ambient air that would otherwise burn the gases coming from the reduction process. The dust-laden furnace gas is withdrawn from under the cover, cleaned, and either used as fuel or flared above the furnace building. The quantity of gas that needs cleaning from a covered furnace can be only 3 to 5 percent of that from an open furnace.

Two types of covered ferroalloy furnaces are currently in operation. Developed in the 1930's, the initial version of the covered ferroalloy furnace has mix seals at the electrodes and is generally called a semi-covered or semi-enclosed furnace (see Figure VII-5). A later version is essentially the same as the earlier one except that tight or fixed seals are used in place of mix seals at the electrodes. This configuration is called a totally enclosed furnace (see Figure VII-6). However, mix seals are maintained within the chutes at the cover of the totally enclosed furnace by choke-feeding the material.

With a semi-enclosed furnace, the mix is charged to the furnace through the annulus around each electrode, and an air gap is established between the furnace cover and the mix chute to prevent an electrical current flow. If enough mix is added to keep this space filled, it acts as a seal that prevents or limits the gases under the cover from escaping through the mix

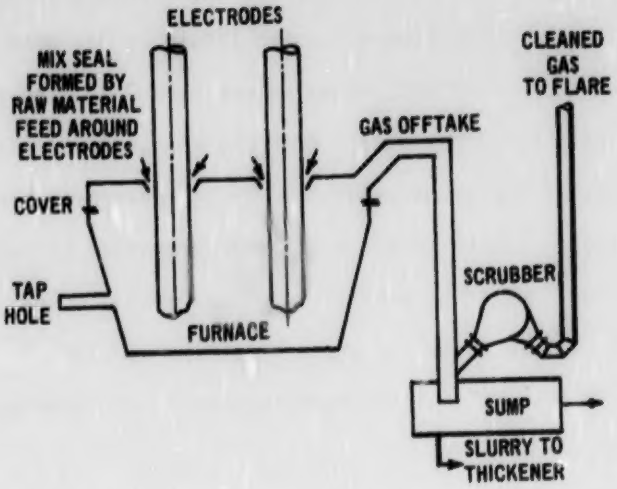

ELECTRODES
MIX SEAL FORMED BY RAW MATERIAL FEED AROUND ELECTRODES
CLEANED GAS TO FLARE
GAS OFFTAKE
COVER
SCRUBBER
TAP HOLE
FURNACE
SUMP
SLURRY TO THICKENER

Figure VII-5. Covered furnace with mix seals.

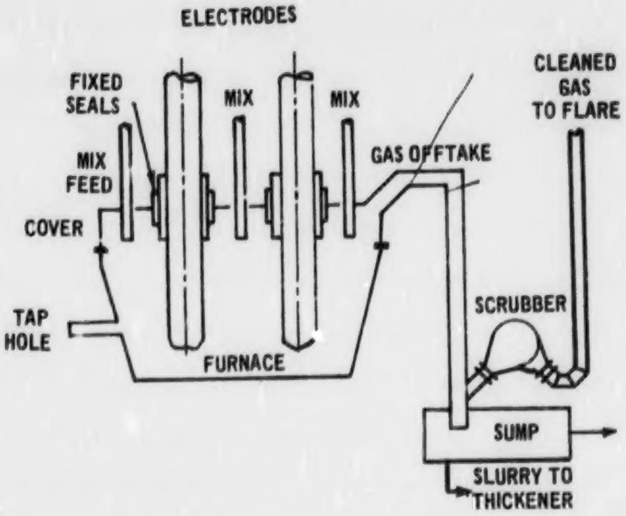

ELECTRODES
FIXED SEALS
MIX
MIX
CLEANED GAS TO FLARE
MIX FEED
GAS OFFTAKE
COVER
SCRUBBER
TAP HOLE
FURNACE
SUMP
SLURRY TO THICKENER

Figure VII-6. Covered furnace with fixed seals.

around the electrodes; hence the term, "mix seals." To minimize emissions at the mix seals, the air pollution control system should be designed with enough flexibility to maintain a slight, negative pressure under the cover. The degree to which furnace emissions escape from the mix seals may also be influenced by the quality of charge materials and by the operating condition of the furnace. Particulate losses from mix seals are reported to range from 2 to 12 percent of the dust and fumes generated in the furnace. Semi-enclosed furnaces are used in the United States to produce calcium carbide, ferrosilicon containing 50, 65, and 75 percent silicon, ferromanganese, silicomanganese, HC ferrochrome, and ferrochrome-silicon.

In a totally enclosed furnace, seals are fixed insulators around the electrodes and cover which allows the air pollution control system to collect essentially all of the dust and fumes. These furnaces are used at several foreign installations to produce calcium carbide, ferromanganese, silicomanganese. ferrochrome, and several grades of ferrosilicon to a limited extent.

No silicon metal or ferrosilicon alloys with 80 to 90 percent silicon are produced in either semi-enclosed or totally enclosed furnaces due to the hot furnace conditions and complications in stoking the furnace.

The quality and size of the raw materials used in the feed mixture have a major influence on the operation of a covered ferroalloy furnace which may adversely affect the gas scrubbing system. Favorable operation requires the use of charge materials with porsity and non-fusing properties that will permit the uniform release of gases from the reduction process and free flow of feed materials into the super-heated zone at the electrode tips. Bridging of the mixture through fusion may cause gas pockets to form within the furnace burden. Upon their collapse, heavy or violent hot-gas blows may suddenly occur which cannot be handled by the gas removal system. Stoking breaks up fused material and controls gas blows. Occasionally, the power may be turned off a semi-enclosed furnace for a short period and the cover doors opened to permit stoking. Totally enclosed furnaces in foreign installations have been found to be rarely if ever stoked. The frequency of stoking in a covered furnace is dependent upon the furnace operating conditions, the type of product, the quality of material, feed preparation, and furnace design.

Nine tests by EPA show that total particulate losses from two semi-enclosed furnaces equipped with scrubbers are higher than the losses from five well-controlled open furnaces and are considerably higher than those from two totally enclosed furnaces equipped with scrubbers. The particulates in the fugitive fumes from the mix seals of the two semi-enclosed furnaces tested averaged 342 lbs/hr and 58 lb/hr respectively. The weight of particulates represented a computed loss of 8.7 percent and 6.7 percent of the total particulates generated in open furnaces of the same size and products based on the emission factors, Table VI-3. A reduction in the fugitive fumes from the two semi-enclosed furnaces tested is required to meet the control equipment performance measured in the other seven EPA tests. Emission reduction may be accomplished by one or more of several methods; improved furnace operation, more advance furnace design, or the use of secondary emission control.

In a covered furnace design using a shaft kiln, 80-90 percent of the dust containing 32.5 percent of MnO from a HC ferromanganese furnace is reported to be retained in the furnace feed mixture and returned to the furnace.[26] As illustrated in Figure VII-7, dust is collected by impaction

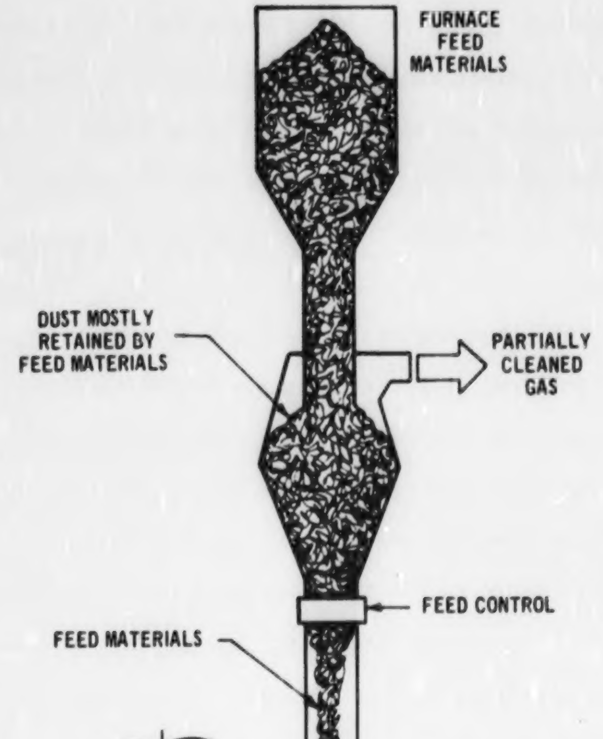
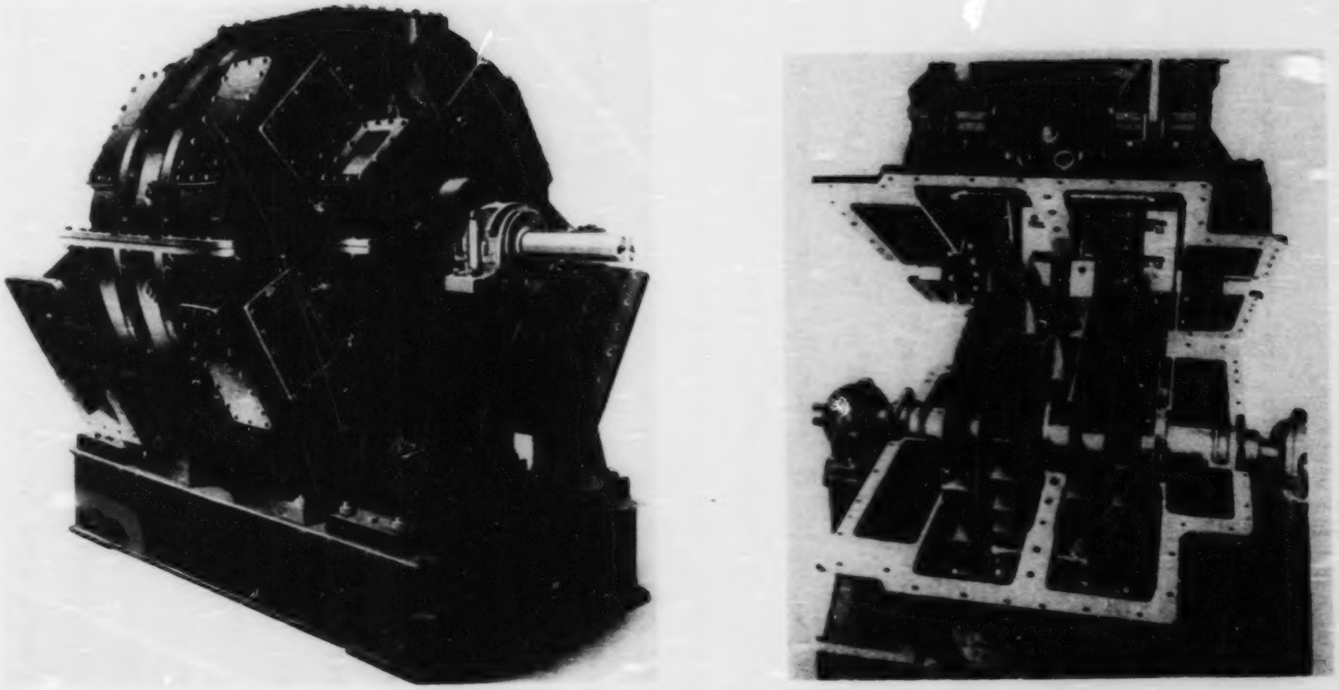

FURNACE
FEED
MATERIALS
DUST MOSTLY
RETAINED BY
FEED MATERIALS
PARTIALLY
CLEANED
GAS
FEED CONTROL
FEED MATERIALS
FURNACE
COVER
DUSTY
GAS
ELECTRODE

Figure VII-7. Shaft kiln on HC ferromanganese furnace.



Rotary multi-stage gas scrubber with bolted ports.

Upper casing lifted on gas scrubber to show multi-stage rotors and sprays.

Figure VII-8. Rotary scrubber used on covered furnaces. (Courtesy of Buffalo Forge Co.)

on the feed as the gas stream is exhausted from the furnace. The benefits of this system have not been verified.

In the United States, gases from semi-enclosed furnaces are often cleaned in a centrifugal scrubber consisting of a multi-stage centrifugal fan equipped with water spray nozzles. The two pictures in Figure VII-8 show the exterior and interior views of a typical centrifugal scrubber used in the ferroalloy industry on several semi-enclosed furnaces. Uncleaned gases enter on the left and after passing through four cleaning states, the cleaned gas is discharged from the "inlet" of the wheel on the right. Although these and other scrubbers generally remove most of the particulates, they do not remove all the tars. Usually, the cleaned gas is flared, and as a result, the tarry material is burned. Absence of visible emissions in the low volume of flared gas indicates that no significant discharge of particulates occurs. However, centrifugal scrubbers are limited to a capacity of about 2800 acfm, which is comparable to gas flowrates from a medium-sized covered furnace. The volumes of gases from larger covered furnaces can be controlled by the use of two or more centrifugal scrubbers. Power and water requirements of a centrifugal scrubber are generally greater than those of a venturi scrubber. A centrifugal gas scrubber when used on a covered furnace that produces calcium carbide and other alloys compatible with the scrubber's limitations, has a particulate removal efficiency of up to 99 percent. Venturi scrubbers currently serving covered furnaces and operating at pressure drops up to 80 inches water have been found to be somewhat more efficient than centrifugal scrubbers.

Scrubbers used to clean the gas from a covered furnace collect the dust in the water. Consequently, treatment facilities are required to remove sludge from the waste water before it is discharged into public waterways.

Cleaned gas from covered ferroalloy or calcium carbide furnaces has significant value as fuel if the gas can be used within a reasonable distance of the furnace. Fuel value of the gas, based on the cost of an equivalent amount of coal, may exceed $100,000 per year for a moderate-sized ferroalloy furnace.

Retrofitting an open furnace to a covered furnace generally cannot be done without completely rebuilding it to include additional head room, which provides space for the cover itself. In addition, head room is required so that the electrode suspension mechanism may be raised to provide working space over the cover. The mixture supply system also requires increased head room since the mixture flows by gravity into the furnace, and the chutes need to be clear of the electrodes. Usually, self-baking electrodes are used for covered furnaces, and ample head room is needed to provide a working area for installing the metal electrode shells and an overhead crane for handling electrode materials.

## D. ELECTROSTATIC PRECIPITATORS SERVING OPEN FURNACES

Theoretically, the electrostatic precipitator has the lowest pressure drop of any large-volume device capable of removing micron-size particles from gas streams. As a result, precipitators usually have lower power and operating costs than other devices of comparable efficiency. Precipitators are also able to operate at higher temperatures than fabric filters. Figure VII-9 shows a cutaway view of a typical high-voltage electrostatic precipitator.

In the precipitation process, particles suspended in the gas are electrically charged and passed through an electric field where electric forces move the particles toward the collection surface. The particles are retained on the collection electrode and subsequently removed from the

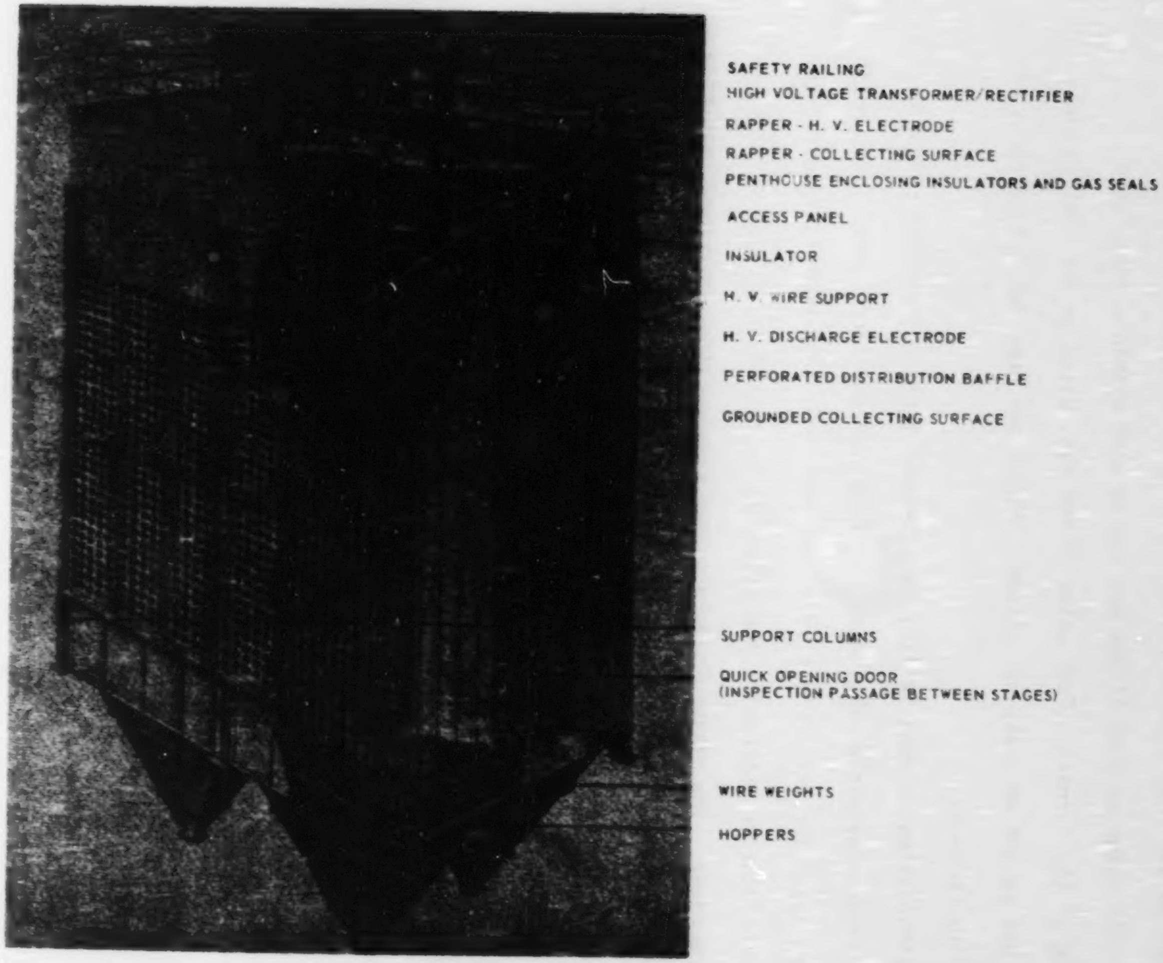

SAFETY RAILING
HIGH VOLTAGE TRANSFORMER/RECTIFIER
RAPPER - H. V. ELECTRODE
RAPPER - COLLECTING SURFACE
PENTHOUSE ENCLOSING INSULATORS AND GAS SEALS
ACCESS PANEL
INSULATOR
H. V. WIRE SUPPORT
H. V. DISCHARGE ELECTRODE
PERFORATED DISTRIBUTION BAFFLE
GROUNDED COLLECTING SURFACE
SUPPORT COLUMNS
QUICK OPENING DOOR
(INSPECTION PASSAGE BETWEEN STAGES)
WIRE WEIGHTS
HOPPERS

Figure VII-9. Cutaway view of a flat surface-type electrostatic precipitator. (Courtesy of UCP Air Correction Division)

precipitator. Various physical configurations are used to accomplish these basic functions of charging, collection, and removal, depending upon the type of application and properties of the dust and gas.

Electrical resistivity of the dust is an important factor in the performance of electrostatic precipitators in the ferroalloy industry. If the resistivity of the collected dust is high, excessive sparking or reverse corona can occur, thereby limiting precipitator performance.

High conductivity of the dust is another property necessary for satisfactory dust removal in a precipitator. Two distinct types of electrical conduction occur. One type is conduction by free electrons within the dust particles. This type of conduction depends upon the electron activation energy, which is a material property varying with temperature. Most of the particulates in the gas streams from the ferroalloy furnaces are composed of metallic oxides and have low activation energies. The electrical conductivity of these particulates is low at temperatures of 300 to 400°F, but is improved substantially when temperatures are between 450 and 500°F.

The second type of conduction occurs over the particle surfaces because of the adsorption of moisture or of certain chemicals such as ammonia. Adsorption increases with decreasing temperature; hence, particle conductivity also increases with decreasing temperature. Moisture is often referred to as the primary conditioning agent, and other chemical adsorbates are called secondary conditioning agents.

Unfortunately, most ferroalloy furnace fumes at temperatures below 500"F have too high an electical resistivity for satisfactory precipitator operation. Resistivity is in an acceptable range only if the gas temperature is maintained above 500"F. The alternative to operating at high temperatures is to humidify the furnace gases along with adding a secondary conditioning agent, like ammonia. Humidification of the furnace gas by water sprays requires good atomization and sufficient residence time and heat to obtain vaporization. Thus, a conditioning tower physically larger than the precipitator may be required (see Figure VII-10). Stainless steel construction would be required for the conditioning tower and interior surfaces of the precipitator in order to control corrosion. The conditioning tower performs like a scrubber and in actuality removes 20 to 30 percent of the particulates from the gas stream. This system thus requires a waste-water disposal system as well.

Only two modern precipitators are in operation on ferroalloy furnaces in the United States. These are on open furnaces. The dust-removal efficiency of these precipitators on open furnaces in the manufacture of chrome alloys under optimal conditions can be expected to be about 98 percent.

## E. WASTE-WATER TREATMENT

Large quantities of water are used in the operation of both the ferroalloy furnaces and the wet-type air pollution control devices (scrubbers and electrostatic precipitators).

Furnace cooling services require by far the largest portion of the water used in ferroalloy manufacturing processes. From 700 to 5,000 gallons per minute may be needed to cool the furnace and certain components of the electrical conductors. Additional water is, of course, required for wet-type air pollution control devices, and approximately one-third of the furnaces in the ferroalloy industry use such devices. For the year 1968, the U.S. Census Bureau tabulated water intake for the electrometallurgical industry (20 out of 34 establishments reporting) as 298.2 billion gallons

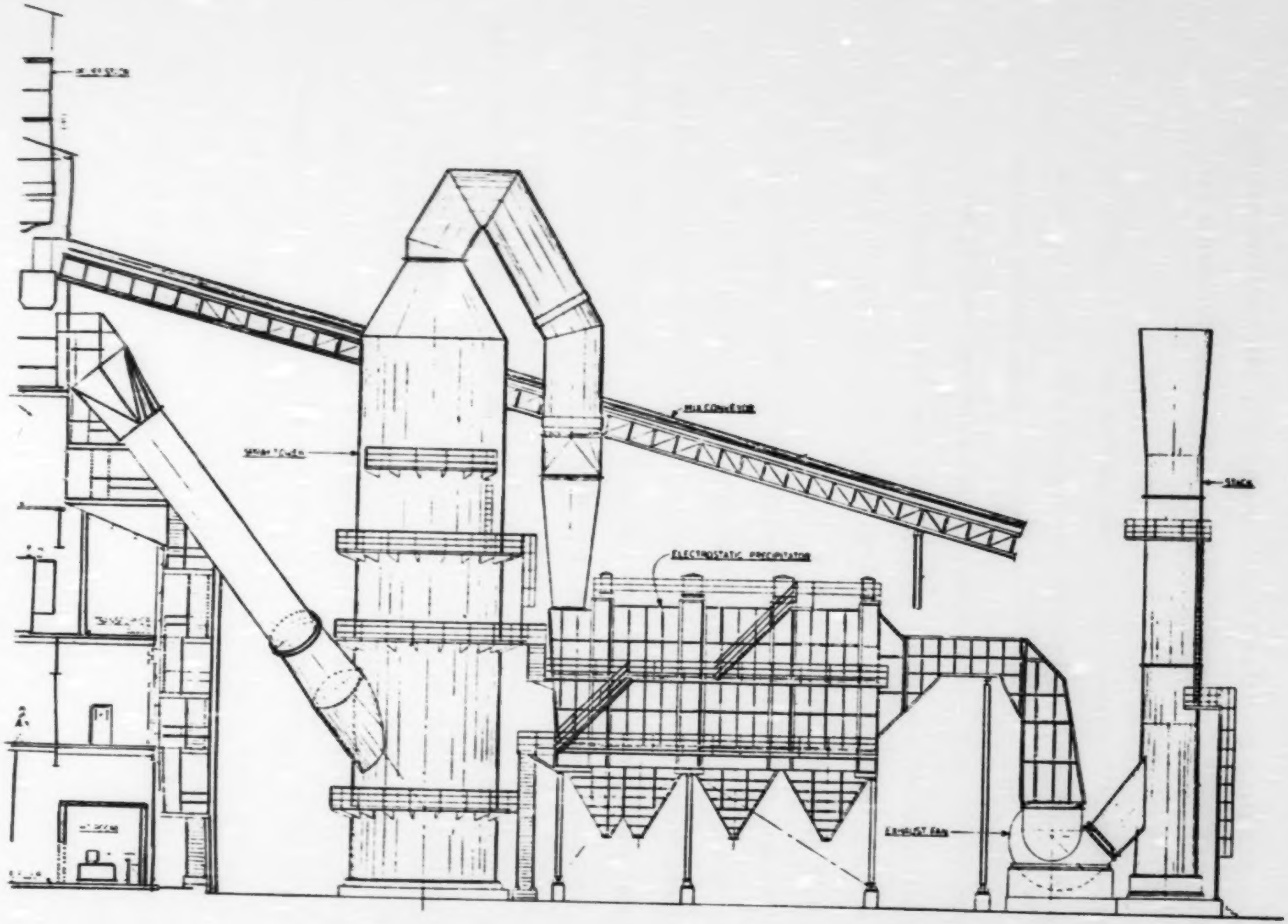

SPRAY TOWER
MIX CONVEYOR
ELECTROSTATIC PRECIPITATOR
STACK
EXHAUST FAN

Figure VII-10. Spray tower in conjunction with electrostatic precipitator.

with gross water usage of 320.3 billion gallons. Since some plants are equipped with their own steam electric generators, 185.3 billion gallons of this total were used for this purpose. Total water discharged was 296.1 billion gallons.

Water quantities needed for furnace cooling and for scrubbers range widely from 3,000 to 10,000 gallons per megawatt-hour and from 500 to 3,500 gallons per megawatt-hour, respectively. Since each ferroalloy plant may differ in its water needs, typical water requirements are difficult to establish. Water use may range from 0.5 million gallons per day for a small plant up to 100 million gallons per day for a large plant with steam electric generators.

Treatment facilities for the scrubber water differ, depending on the product being made and the type of scrubber system used. Water pollutants from a ferroalloy plant may include one or more of the following: suspended insoluble metal compounds, soluble metal compounds, cyanides, acid or basic effluents, tars, and thermal pollution. Chemical and physical treatment of the waste streams is usually sufficient; biological treatment methods are not normally considered necessary. Scrubber water is always clarified to remove the dust scrubbed from the ferroalloy furnace fumes. The solids consist of burden fines ranging from less than 1 micron up to 10 microns. The slurry bleed-off rate from a scrubber ranges from 200 to 500 gallons per minute. Concentration of suspended solids in the slurry bleed-off varies considerably not only from plant to plant but also from hour to hour from the same ferroalloy furnace; a typical range is 3,000 to 17,000 ppm. A well-designed clarifier can reduce the concentration of suspended solids to less than 50 ppm.[29]

In some plants, thickened sludge from the clarifier is dewatered by vacuum filters. In some foreign installations, dewatered solids are sintered and recycled to the furnace. In the sintering plant, sludge is blended with other fines and fired on grates in a furnace to produce a clinkerlike material that can be recharged to the ferroalloy furnace. Sintering is used in some ferroalloy plants outside of the United States.

The scrubber water also dissolves and entrains contaminants which may include cyanide and carbon monoxide. In one European plant where the clarifier was located inside a building, carbon monoxide escaping from the clarifier exposed workers to excessive levels of carbon monoxide. This problem was solved by installing a ventilation system. Cyanides are found in the water from scrubber systems serving covered furnaces. Cyanide removal is generally effected by the stagewise application of lime and chlorine, which break down the cyanides and related compounds to carbon dioxide and nitrogen. Unless the sludge has some recycle value, it is pumped to settling ponds. These ponds may cover several acres, which are filled solidly up to 30 feet deep. When located near rivers, they may require monitoring to detect seepage.

Figure VII-11 shows a flow diagram of a typical waste-water treatment facility. Because cyanide is not always present in the effluent, the cyanide removal part of this system is shown by broken lines.

The Federal Water Pollution Control Act Amendments of 1972 require EPA to establish effluent limitation that must be achieved by point sources of discharges into navigable waters of the United States. Section 301

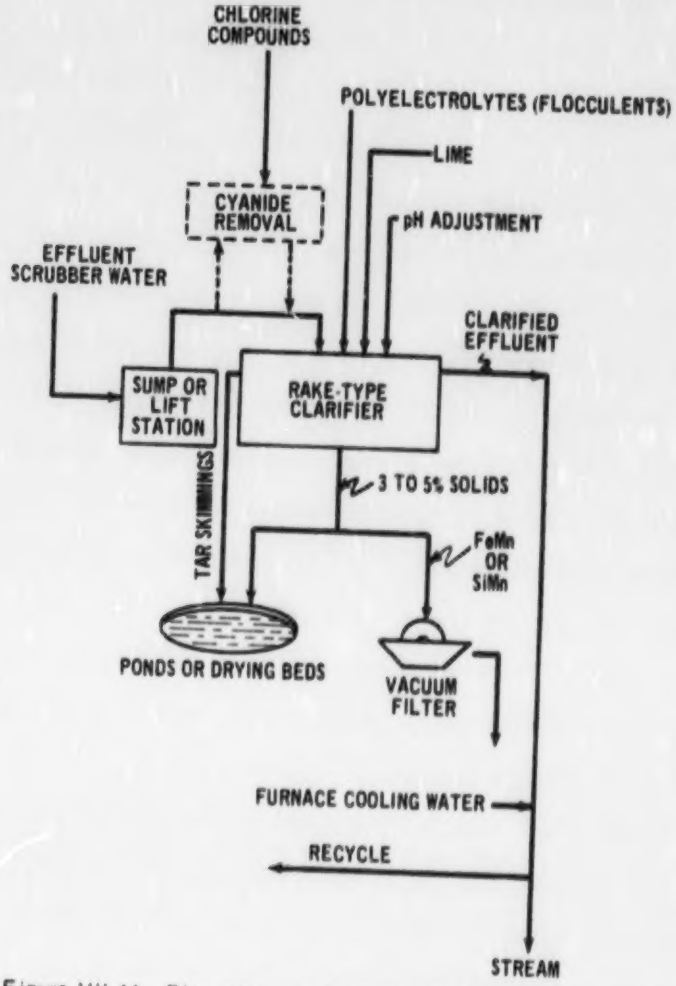

CHLORINE COMPOUNDS
POLYELECTROLYTES (FLOCCULENTS)
LIME
CYANIDE REMOVAL
pH ADJUSTMENT
EFFLUENT SCRUBBER WATER
CLARIFIED EFFLUENT
SUMP OR LIFT STATION
RAKE-TYPE CLARIFIER
3 TO 5% SOLIDS
TAR SKIMMINGS
FeMn OR SiMn
PONDS OR DRYING BEDS
VACUUM FILTER
FURNACE COOLING WATER
RECYCLE
STREAM

Figure VII-11. Flow diagram of typical waste-water treatment facility.

of the Act requires the achievement by July 1, 1977, of effluent limitations which require application of the "best practicable control technology currently available," and the achievement by July 1, 1983, of effluent limitations which require application of the "best available technology economically achievable." In addition to setting effluent standards for existing point sources, EPA also sets standards for new point sources.

## F. SOLID WASTE DISPOSAL

The application of more highly efficient air pollution and waste-water treatment facilities in the industry intensifies the solid waste problem. This means that wet and dry air pollution control equipment that is only 95 percent efficient will potentially collect 342,000 tons per year of solid waste. The industry also disposes of slag when it cannot be used in other processes. The industry produces about 450,000 tons per year of slag. Slag from some operations is crushed and used as road material. Also, waste slag from ferroalloy manufacture has been used to construct docks and reclaim land.

Presently very little use is made of collected ferroalloy particulates. Most of the collected dust is deposited in refuse lagoons and landfill areas. In the dry state the collected material, which contains considerable quantities of submicron fumes, can easily become reentrained when transported to open dumps. Therefore, dust collected in the dry state should be mixed with water or pelletized before disposal.

# VIII. EMISSION CONTROL GUIDELINES

## A. FIELD SURVEILLANCE GUIDELINES FOR AIR POLLUTION CONTROL OFFICIALS

### 1. Typical Emission Control Regulations Pertaining to the Ferroalloy Industry

Particulate matter is the principal air contaminant emitted by ferroalloy plants. These particulates are primarily metallic oxides and originate mainly from the electric smelting process. Unless adequately controlled, ferroalloy plant emissions are usually noticeable as a cloud mass formed from several individual plumes and, depending upon weather conditions, can prevail downwind for several miles. Most of the particulates are submicron in size and produce extensive light scattering; consequently, low particulate concentrations are necessary before the furnace fumes become invisible.

Most state regulations pertaining to allowed particulate emissions are based on the weight of materials introduced into a specific process. Table VIII-1 summarizes the general regulations for the states where most ferroalloy plants are located. The regulations express allowable emissions in pounds of particulate matter that can be emitted per hour as a function of the total pounds per hour of raw material process weight rate. Included in this table is the percent opacity allowed by those states that have opacity restrictions.

Table VIII-1. STATE REGULATIONS OF ALLOWABLE EMISSIONS FROM GENERAL PROCESS SOURCES

(lb particulate/hr)

| State | Process weight rate, lb/hr | | | | | | | | | | Visible emissions, % opacity |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 100 | 1000 | 5000 | 10,000 | 20,000 | 40,000 | 60,000 | 120,000 | 200,000 | 1,000,000 | |
| Alabama[a] | 0.56 | 2.34 | 6.33 | 9.76 | 14.97 | - | 29.83 | 33.33 | 36.17 | 46.97 | 20[b] |
| Iowa | 0.55 | 2.58 | 7.58 | 12.00 | 19.20 | 30.5 | 40.0 | 46.3 | 51.2 | 69.0 | |
| Kentucky | 0.55 | 2.58 | 7.58 | 12.00 | 19.20 | 30.5 | 40.0 | 46.3 | 51.2 | 69.0 | |
| Mississippi | 0.55 | 2.58 | 7.58 | 12.00 | 19.20 | 30.5 | 40.0 | 63.7 | 89.7 | 264.0 | 40[b] |
| New York | 0.5 | 2.3 | 6.7 | 10.8 | - | - | 31.8[c] | - | - | 71.1 | |
| Ohio | 0.55 | 2.58 | 7.58 | 12.00 | 19.20 | 30.5 | 40.0 | 46.3 | 51.2 | 69.0 | 20[b] |
| Oklahoma | 0.55 | 2.58 | 7.58 | 12.00 | 19.2 | 30.5 | 40.0 | 46.3 | 51.2 | 69.0 | |
| Oregon | 0.46 | 2.80 | 6.67 | 10.00 | 16.19 | 28.3 | 40.0 | 46.3 | 51.2 | 69.0 | |
| Pennsylvania[d] | | | | | | | | | | | |
| S. Carolina | 0.55 | 2.58 | 7.58 | 12.00 | 19.2 | 30.5 | 40.0 | 46.3 | 51.2 | 69.0 | 20[e] |
| Tennessee[f] | 0.55 | 2.34 | 6.34 | 9.70 | 15.0 | 23.0 | 29.6 | 33.3 | 36.1 | 46.7 | 20[e] |
| Texas | - | 1.6 | 7.7 | 15.2 | 30.1 | 59.7 | 67.4 | - | 95.2 | 123.9 | |
| Washington | 0.55 | 2.25 | 6.34 | 9.73 | 14.99 | - | 29.6 | 33.28 | 36.11 | 69 0 | 20 |
| West Virginia[g] | | | | | | | | | | | 20 |

[a] For Class I counties only. Class II counties very similar to Iowa.

[b] Maximum of 60 percent opacity allowed for 3 minutes in any one hour.

[c] For 50,000 lb/hr.

[d] Allowable emissions based on the following formula:
$A = 0.76E^{0.42}$, where
A = Allowable emissions in lb/hr.
E = Emission index = F X W lb/hr.
F = Process factor in lb/unit (factor for ferroalloy = 0.3)
W = Process rate, lb/hr.

[e] For new equipment; 40 percent allowed for existing equipment.

[f] For new plants only. Existing plants same as South Carolina.

[g] Process weight based on "Source Operation" or a "Duplicate Source Operation."

Since process weights are not easily obtained for electric smelting furnaces, an indirect approach can be used with reasonable success. This approach is based on the stoichiometry of ferroalloy smelting, which provides a relationship between process weight and electrical energy input (obtainable from control room instruments) required to produce a unit weight of product. These relationships are expressed as factors that vary with the product made and are shown in Table VIII-2. This table provides the range of raw material usage and electrical energy requirements experienced in furnaces normally used to produce general classes of ferroalloys. Average factors are shown for convenience in applying them to process weight information and furnace capacity in megawatts.

Process weight (in pounds per hour) for each individual product in Table VIII-2 may be determined by multiplying the average integrated furnace load in megawatt-hours (obtained from instruments at the furnace) by the appropriate factor from the table (column 7). Likewise, net tons of the ferroalloy produced may be determined by multiplying the average integrated furnace load in megawatt-hours by the listed factor (column 6). Uncontrolled mass-rate emissions may then be estimated by multiplying the net tons of ferroalloy produced by the emission factor shown for the appropriate ferroalloy in Table VI-3.

State emission control regulations for particulates vary to some degree but are generally based on process weight for each operating furnace or source. Because they do vary, however, a careful study of the emission control regulations and a general knowledge of the plant operation, including furnace loads and products, are needed to determine allowed

## Table VIII-2. FACTORS FOR PROCESS WEIGHTS AND FERROALLOY PRODUCTION RELATED TO FURNACE KILOWATT CAPACITY

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| | Charge weight, lb/lb alloy | | Furnace load, KW-hr/lb alloy | | | |
| Product | Range | Approximate average | Range | Approximate average | Product, lb/Mw-hr | Charge weight, lb/Mw-hr |
| Silvery iron | 1.7-1.9 | 1.8 | 1.2-1.4 | 1.3 | 770 | 1380 |
| 50% FeSi | 2.3-2.5 | 2.5 | 2.4-2.5 | 2.5 | 400 | 1000 |
| 65-75% FeSi | 4.3-4.5 | 3.6 | 4.2-4.5 | 4.4 | 227 | 1020 |
| Silicon metal | 4.6-5.0 | 4.9 | 6.0-8.0 | 7.0 | 144 | 700 |
| SMZ | 4.3-4.5 | 4.5 | 4.2-4.5 | 4.4 | 227 | 1020 |
| CaSi | 3.8-4.0 | 3.9 | 5.7-6.1 | 5.9 | 170 | 660 |
| HC FeMn | 2.9-3.3 | 3.0 | 1.0-1.2 | 1.2 | 834 | 2500 |
| SiMn | 2.7-3.3 | 3.1 | 2.0-2.3 | 2.2 | 454 | 1410 |
| FeMnSi | 4.2-4.4 | 4.3 | 2.4-3.0 | 2.7 | 370 | 1590 |
| Mn ore/lime melt | 3.2-3.6 | 3.5 | 0.6-1.0 | 0.8 | 1350 | 4280 |
| Chg Cr | 3.7-4.1 | 4.0 | 2.0-2.2 | 2.1 | 476 | 1900 |
| HC FeCr | 3.7-4.1 | 4.0 | 2.0-2.2 | 2.1 | 476 | 1900 |
| Cr ore/lime melt | | 1.2 | 0.5-0.7 | 0.6 | 1670 | 2000 |
| FeCrSi | 3.2-3.6 | 3.4 | 3.6-3.8 | 3.7 | 270 | 920 |
| Ca carbide | 1.5-1.7 | 1.6 | 1.3-1.4 | 1.3 | 770 | 1230 |

losses from each individual plant.

## 2. Process Description and Sources of Emissions

A general description of the ferroalloy industry has been given in Chapter V. The operations important to the air pollution control inspector are the submerged-arc furnaces, the raw material preparation and handling system, and the product sizing and handling. Figure VI-1 in Chapter VI shows a typical flow diagram for ferroalloy production.

Ferroalloys are alloys of iron and some other metal or metals, such as manganese, chromium and silicon. They are produced by reducing an ore of the alloying element with carbon in the presence of heat and iron from scrap steel. A submerged-arc furnace provides the high-temperature vessel for the carbon reduction process. Furnaces are rated by electrical energy input and vary in size from about 7,000 to 50,000 kilowatts, depending upon furnace use and age.

Raw materials from open storage piles are conveyed to overhead bins in the mix house, where charge material is mixed and weighed for each individual furnace. The lump size of the raw materials varies from approximately 0.25 to 4 inches. In some plants, part of the mix materials are dried before they are conveyed to the mix house; in this case, up to 3 percent of the material charged may be lost as particulate unless proper air pollution control equipment is used. However, under ordinary circumstances when no intermediate operations are performed, the dust generated during conveyance of material to the mix house can be held to a low level with proper handling.

Raw materials in the mix house are weighed into larry cars or conveyors according to the mix required for product specifications. The small amount of dust generated during mix preparation is generally confined to the mix house. The larry car next dumps the mix into a skip hoist, which in turn lifts the contents to an overhead belt conveyor within the furnace building. If there are several furnaces within the building, the conveying system is designed to transport the mix to the correct furnace mix bins. Charge material from the overhead mix bins is normally gravity-fed into the furnace through several enclosed chutes, although a few open furnaces charge mix materials with manually operated skip loaders.

The principal source of emissions is the submerged-arc furnace. Emissions vary widely in type and quantity, depending upon the product being made, the type of furnace used, and the power input to the furnace. Gas containing large quantities of carbon monoxide, metallic oxide fumes, and dust is continuously generated; gas flow will vary with furnace operation. In an open furnace, large gas volumes result when the carbon monoxide is burned to carbon dioxide at the surface of the charge. In a covered furnace, the unburned carbon monoxide is withdrawn and may be used as fuel or flared.

Another source of fumes associated with ferroalloy furnaces is the tapping operation, which occurs every 1 to 5 hours, depending on the product, and lasts for 10 to 15 minutes. After being tapped into a ladle, the molten material may be transferred by overhead crane to another ladle for repouring, which results in additional fume emissions. In some processes, still additional ladle operations involve slag-metal reactions, chlorination, and oxidation, all of which produce emissions.

The molten product is poured into chills or molds, during which time fumes are generated. After solidifying in chills, the product is either manually sized or mechanically crushed and screened to size before shipment. The crushing and sizing system (jaw crushers, cone crushers and screens) generates sufficient dust to require an air pollution control system.

### 3. Emission Control Systems

Emission control systems are described in Chapters VI and VII. The major emission problem of the ferroalloy industry concerns the capture and collection of fumes from electric furnaces. Control sytems are in use on both open and covered furnaces. Fumes from an open furnace are collected by a canopy hood located 5 to 6 feet above the furnace and are ducted through stacks to an emission control device. The combustion taking place at the surface of the unreacted charge material results in large quantities of gases.

Most conventional control devices have been used on open furnaces. Several push-through baghouses are used on open furnaces producing different products and, in the absence of other suitable devices, have been found to be particularly adaptable for silicon metal and high-silicon alloys. High-energy scrubbers are used on furnaces producing silicomanganese, HC ferrochrome, and ferrochrome-silicon. Two electrostatic precipitators are in service on domestic furnaces producing HC ferrochrome and ferrochrome-silicon.

Particulate emission rates from the better controlled open furnaces in the United States range from 1.0 to 1.5 pounds per megawatt-hour. Particulate emission rates from the most efficient air pollution control systems cleaning collected gases from semi-enclosed furnaces are much lower, ranging up to 0.1

pound per megawatt-hour. Unless losses from the mix seals are controlled however, semi-enclosed furnaces generally are not as well controlled as the better controlled open furnaces.

The covered furnace restricts air ingestion so that the reaction gases, consisting of a high percentage of carbon monoxide, are mostly unburned. Gas quantities from a covered furnace are from 2 to 5 percent of those from an equivalent-size open furnace. Consequently, a control device serving a closed furnace is small compared to one on an open furnace. High-energy venturi scrubbers and centrifugal scrubbers are generally used to control emissions from covered furnaces.

All ferroalloy products cannot presently be produced in covered furnaces. The semi-enclosed furnace (with mix seals) is used in the United States for the production of calcium carbide, HC ferromanganese, silicomanganese, 50-percent ferrosilicon, and several other ferroalloys with relatively low gas evolution. In general, however, the high-silicon alloys (75 percent silicon and higher) and silicon metal are not produced in covered furnaces either in the United States or abroad.

### 4. Maintenance and Operating Problems

Even the most effective emission control systems in the ferroalloy industry, whether serving open or covered furnaces, occasionally will have operating problems during which the allowed losses may be exceeded. These operating problems may be caused by equipment failures, plugged ducts, electrical difficulties, or some other type of problem. In some instances, the proper performance of the control equipment bears a direct relationship to the manner in which the furnace is operated. For example, if rough furnace operation suddenly increases the normal exhaust gas temperature, the performance of an electrostatic precipitator may be adversely affected.

Ferroalloy furnaces are costly and complicated pieces of heavy equipment that require a well-planned maintenance program. Their operation requires large quantities of selected feed materials, considerable amounts of electrical power that is converted into heat, and rapidly circulated cooling water to prevent heat damage to the equipment. The complexity of the furnaces causes some operating problems even when the equipment is operated by qualified personnel and preventive maintenance is performed.

Principal furnace operating problems may involve equipment failures, furnace tapping problems that may cause the electrodes to be higher than normal, water leaks, furnace interruptions for equipment repairs followed by startup periods, mixture feed problems, electrode failures, electrical difficulties, and electrical power shortages. Although the majority of furnace operating problems cause interruptions of less than an hour, major furnace operating difficulties do occur and production may then be interrupted for several days. When a furnace with a cold hearth is starting up after a long shutdown, emissions will be heavier than normal for up to a week. In general, ferroalloy furnaces operate from 90 to 95 percent of the time on an annual basis.

Baghouses usually contain several thousand cloth bags with a usable life of about 2 years. Bags are normally replaced as they wear out; replacement may be necessary daily. Sometimes locating the torn bags requires a prolonged search, frequently under limited light conditions.

Scrubber systems use large exhaust fan motors to drive high-speed fans that require continuous monitoring because imbalances may occur. Close control of the scrubber system's water supply is also necessary to ensure desired performance. Both recirculated water and waste water require treatment before discharge.

When electrostatic precipitators are used, the gas usually requires preconditioning before passing through the electrical fields of the precipitator in order to reduce electrical resistivity of the particulate matter. Monitoring is necessary to ensure that the gas is correctly preconditioned. Other reasons the precipitators may not achieve design efficiency are improper gas flow, inadequate rapping, electrode misalignment, adhesion of collected material to interior surfaces, blocked hoppers, and failure of the high-voltage electrical supply. Most ferroalloy furnaces are capable of producing different products, but the high resistivity of some fumes may prevent a precipitator from attaining required collection efficiency.

### 5. Monitoring Instruments

Because emission monitoring instruments are complex and difficult to maintain, they are used on only a limited basis in the ferroalloy industry. Opacity meters, which measure the attenuation of light beams caused by particulate matter suspended in stack gases, are used to a limited extent. To have reliable readings these instruments must be cleaned frequently. Although continuous monitoring instruments indicating the mass emission rate of particulates are available on the market, the adequacy of these instruments for use in the ferroalloy industry has not been fully demonstrated.

Newer furnaces usually have emission control equipment, sample ports in the exhaust ducts, and platforms and ladders to permit stack sampling.

The furnace kilowatt-hour meter or kilowatt-load chart is used to determine quantities of electrical energy consumed by furnace operation.

Usually, no other process control instruments can be related to the furnace production rates or process charge weights. Furnace production rates and process weight rates can be computed from the furnace power consumption, as shown in Table VI-4.

## B. PROCEDURES FOR REDUCING EMISSIONS DURING EMERGENCY AIR POLLUTION EPISODES

Air pollution control measures are promulgated to meet national ambient air quality standards during normal meteorological conditions. However, adverse meteorological conditions may cause a buildup of air pollutants. To avoid a catastrophe in this event, each State is responsible for establishing emergency episode procedures. These State procedures will be necessary until emergency provisions of the Clean Air Act Amendments of 1970 have been fully implemented.

The objective of an emergency episode plan is the immediate reduction of emissions. Control strategies specify the control actions and the degree of control required for each source. These measures are necessarily selective, requiring emergency curtailment of nonessential, easily controlled sources first and postponing drastic measures until initial curtailments are obviously insufficient.

Following is an example of an episode criteria plan used as a guide for conditions justifying the proclamation of an air pollution alert, air pollution warning, or air pollution emergency:[30]

(a) "Air Pollution Forecast": An internal watch by the Department of Air Pollution Control shall be actuated by a National Weather Service advisory that Atmospheric Stagnation Advisory is in effect or the equivalent local forecast of stagnant atmospheric condition.

(b) "Alert": The Alert level is that concentration of pollutants at which first stage control actions are to begin. An Alert will be declared when any one of the following levels is reached at any monitoring site:

$SO_2$ -- 800 $\mu g/m^3$ (0.3 p.p.m.), 24-hour average.

Particulate -- 3.0 COHs or 375 $\mu g/m^3$, 24-hour average.

$SO_2$ and particulate combined -- product of $SO_2$ p.p.m., 24-hour average, and COHs equal to 0.2 or product of $SO_2$ -- $\mu g/m^3$, 24-hour average, and particulate $\mu g/m^3$, 24-hour average equal to 65 X $10^3$.

CO -- 17 $mg/m^3$ (15 p.p.m.), 8-hour average.

Oxidant ($O_3$) -- 200 $\mu g/m^3$ (0.1 p.p.m.) -- 1-hour average.

$NO_2$ -- 1130 $\mu g/m^3$ (0.6 p.p.m.), 1-hour average, 282 $\mu g/m^3$ (0.15 p.p.m.), 24-hour average.

and meteorological conditions are such the pollutant concentration can be expected to remain at the above levels for twelve (12) or more hours or increase unless control actions are taken.

(c) "Warning": The warning level indicates that air quality is continuing to degrade and that additional control actions are necessary. A warning will be declared when any one of the following levels is reached at any monitoring site:

$SO_2$ -- 1,600 $\mu g/m^3$ (0.6 p.p.m.) 24-hour average.

Particulate -- 5.0 COHs or 625 $\mu g/m^3$, 24-hour average.

$SO_2$ and particulate combined -- product of $SO_2$ p.p.m., 24-hour average and COHs equal to 0.8 or product of $SO_2$ $\mu g/m^3$, 24-hour average and particulate $\mu g/m^3$, 24-hour average equal to 261 X $10^3$.

CO -- 34 $mg/m^3$ (30 p.p.m.),8-hour average.

Oxidant ($O_3$) -- 800 $\mu g/m^3$ (0.4 p.p.m.), 1-hour average.

$NO_2$ -- 2,260 $\mu g/m^3$ (1.2 p.p.m.) -- 1-hour average; 565 $\mu g/m^3$ (0.3 p.p.m.), 24-hour average.

and meteorological conditions are such that pollutant concentrations can be expected to remain at the above levels for twelve (12) or more hours or increase unless control actions are taken.

(d) "Emergency": The emergency level indicates that air quality is continuing to degrade toward a level of significant harm to the health of persons and that the most stringent control actions are necessary. An emergency will be declared when any one of the following levels is reached at any monitoring site:

$SO_2$ -- 2,100 $\mu g/m^3$ (0.8 p.p.m.), 24-hour average.

Particulate -- 7.0 COHs or 875 $\mu g/m^3$, 24-hour average.

$SO_2$ and particulate combined -- product of $SO_2$ p.p.m., 24-hour average and COHs equal to 1.2 or product of $SO_2$ $\mu g/m^3$. 24-hour average and particulate $\mu g/m^3$, 24-hour average equal to $393 \times 10^3$.

CO -- 46 $mg/m^3$ (40 p.p.m.), 8-hour average.

Oxidant ($O_3$) -- 1,200 $\mu g/m^3$ (0.6 p.p.m.), 1-hour average.

$NO_2$ -- 3,000 $\mu g/m^3$ (1.6 p.p.m.), 1-hour average; 750 $\mu g/m^3$ (0.4 p.p.m.), 24-hour average.

and meteorological conditions are such that this condition can be expected to remain at the above levels for twelve (12) or more hours.

(e) "Termination": Once declared, any status reached by application of these criteria will remain in effect until the criteria for that level are no longer met. At such time, the next lower status will be assumed.

Additional information relative to air pollution emergency episodes is reported in the Federal Register, August 14, 1971, and the amendment of October 23, 1971.

A ferroalloy plant can curtail atmospheric pollution during an episode in a number of ways:

1. A plant with both well-controlled and uncontrolled furnaces should shut down the uncontrolled furnace(s) first.
2. A plant with no controlled furnaces should consider shutting down one or more furnaces in preference to an overall reduction of loads. The worst polluting furnaces should be the first to

be shut down. For example, if there are four furnaces and a 25-percent reduction in emissions is required, better emission reduction can be attained by shutting down one of the furnaces than by cutting the operating load 25 percent on all four furnaces. Also, the furnace with the highest emission levels to the atmosphere should be the first to shut down.

3. Curtail or stop the material handling system as much as possible.
4. Curtail or stop the alloy sizing operations.

Furnaces can shut down almost immediately by stopping the electrical power input. Once this is done, emissions are immediately lowered substantially and will gradually disappear over a few hours.

# IX. ECONOMICS OF EMISSION CONTROL

## A. INTRODUCTION

Under the Clean Air Act (1970) each State has the primary responsibility for assuring air quality within the geographic confines of that State by formulating and adopting, after formal approval by the Administrator of the Environmental Protection Agency, implementation plans for achievement of primary and secondary ambient air quality standards. These plans contain emission regulations and timetables of compliance for industrial sources, among other provisions, such as monitoring air quality and enforcement, for the attainment of the ambient air quality standards.

Ferroalloy plants are subject to implementation plans as required under the Clean Air Act. Air pollution control equipment has been installed in a few plants for the past several years. This chapter is a study of the better controlled facilities in the industry. It provides that basis for estimating the investments and annual expenditures that will be incurred over the next two to three years to meet emission regulations that will be adopted by state implementation plans.

To provide a general economic profile of the industry, present ownership, type, and location of plants will be given. Three major products--ferromanganese, ferrochromium, and ferrosilicon--will be analyzed for supply-demand characteristics, growth, and price movements. Model plants will then be presented along with their control requirements, associated investment costs, and annualized costs. Finally, economic repercussions will be discussed in terms of impact on income and the ability of the firm to pass along the costs.

In order to reduce labor costs and to remain competitive, the ferroalloy industry in the United States in recent years has constructed very large submerged-arc furnaces with well-developed mechanical equipment for handling raw materials and the finished product. The more efficient furnaces are expected to be retrofitted with control devices such as baghouses and high-energy scrubbers. A number of smaller, inefficient furnaces may be shut down and replaced with larger furnaces (e.g., a single new furnace of 30,000 to 50,000 kw size replacing several smaller existing furnaces).

## B. ECONOMIC PROFILE

### 1. Introduction

The economic scope of the ferroalloy industry is international and highly complex. Probably no other activity linked to steel making is so completely subject to the forces of world trade. Normally the ores and other raw materials, the finished ferroalloys, and even the final steel products are all international commodities. More than 50 different alloys and metals, in hundreds of various compositions and sizes, are produced for use in the manufacture of iron, steel, and nonferrous metals. Most of the products are classified into three general groups--ferromanganese, ferrochromium, and ferrosilicon. This sector of the chapter will present a picture of the industry's structure followed by an analysis of the current economic situation for each of the three major product groups. An estimation of the frequency of new installations will also be made.

### 2. Industry Structure

The ferroalloy industry is comprised of establishments that reduce oxidic ores with carbon, for the most part, to obtain the various ferroalloy products. The sources of carbon are most commonly byproduct coke or low-volatile coals. The ores are either imported, like manganese or chromium ores used to produce ferromanganese and ferrochromium, or mined domestically, like quartz used to produce ferrosilicon. After reduction in the electric furnace, the product is cast and crushed to meet consumer specifications.

As of January 1, 1972, there were approximately 44 known plants in the United States, owned by 24 firms. Table IV-1 outlines plant ownership, geographic location, general run of products, and types and numbers of furnaces producing both ferroalloys and calcium carbide. As shown, there are 145 ferroalloy furnaces and 13 calcium carbide furnaces. This tabulation should be reasonably accurate, although the companies involved frequently change their product lines or take furnaces in and out of production according to demand.

The smaller ferroalloy companies are not diversified and rely principally on sales of ferroalloys for their income. The larger companies, however, have other interests, such as the manufacture of industrial gases, chemicals, and steel, and their ferroalloy sales comprise only a part of their income. In any case, the cost of controlling emissions to atmosphere to meet new air pollution standards will have a major effect on ferroalloy production costs and may force closure of marginal ferroalloy plants, especially those that have open furnaces with no dust hoods and ductwork for handling the furnace's gaseous emissions. Furnaces of this type cannot be effectively equipped with emission control equipment without completely rebuilding the furnace and extending the building height to provide the head room required for the dust hood, ducts, and more mechanized electrode columns. Rebuilding a ferroalloy furnace requires substantial new capital investment, and currently weak markets for ferroalloys do not justify such an investment.

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### a. Ferromanganese - Silicomanganese

The Ore - Except for a small quantity of metallurgical oxide nodules shipped from stocks by The Anaconda Company and made several years ago from Montana carbonate ore, no manganese ore, concentrates, or nodules have been produced or shipped in the United States since 1971. Thus the U.S. is now totally dependent on foreign sources of manganese ore. The effect of recent monetary fluctuations on ore prices is not known. Principal suppliers are Africa, 50 percent; Brazil, 30 percent; and India, 5 percent. None of the countries is noted for its hard currency. Table IX-1 traces the recent volume and price history of manganese ore supplies.

Under the "Kennedy round" of General Agreement on Tariffs and Trade (GATT), tariffs were reduced on January 1, 1972, from 0.22 cent per pound of contained manganese to 0.12 cent per pound. Actually, with only one exception, no tariffs have been imposed since June 1964 because of congressionally approved suspensions. The exception is a special tariff of 1.0 cent per pound of contained manganese on ores from the U.S.S.R. and mainland China, deterring their import.

U.S. consumption of metallurgical-grade ore has been cyclical, depending upon the domestic market situation for ferromanganese and steel. The market for ores became progressively weaker during the latter half of the sixties, and imports generally decreased. Prices followed the downward trend, with the average value of imports at the foreign port falling from $34 per gross-weight ton in 1962 to $22 in 1971, a drop of 35 percent. All manganese ore prices are negotiated because they are dependent, in part, on the characteristics and quantity of ore offered, delivery terms, and

Table IX-1. SOURCES AND VALUES OF ORES CONTAINING 35 OR MORE PERCENT MANGANESE, 1962-1971[3]

| Year | U.S. production, short tons x $10^3$ | Imports (gross weight), short tons x $10^3$ | Value,[a] $/ton |
|---|---|---|---|
| 1971 | b | 1914 | 22 |
| 1970 | 5 | 1735 | 20 |
| 1969 | 6 | 1960 | 20 |
| 1968 | 11 | 1828 | 25 |
| 1967 | 13 | 2059 | 27 |
| 1966 | 14 | 2554 | 30 |
| 1965 | 29 | 2575 | 43 |
| 1964 | 26 | 2064 | 37 |
| 1963 | 11 | 2093 | 32 |
| 1962 | 25 | 1970 | 34 |

[a] At foreign port.

[b] 1971 production 142 tons.

fluctuating shipping rates. Transportation is a major cost item, with ocean freight rates comprising roughly one-third of the price of imported ore at eastern seaports. Including domestic rail transportation, the price of ore now reaching the domestic processing plant is probably about $30 per gross ton.

The outlook is for price stability in the world markets. At present, supply about equals demand and prices should halt their decline. Current and near-term prices are showing some strength. The Bureau of Mines estimates that nearly stable prices are expected to prevail through the end of the century. Given current technology and projected growth rates for steel, by the year 2000 the U.S. may need over 3.5 million tons of ore per year.

The Product - Over 90 percent of the imported manganese ore is used to make ferromanganese (75 percent) and other alloys (15 percent). The consumption of ferromanganese and silicomanganese is tied closely to the steel industry, which consumes 95 percent of the output. These alloys are needed principally to counteract the effects of sulfur in cast iron and steel. They also improve the characteristics of steel during rolling and add strength and toughness to the finished product. The remaining 5 percent of the output is used in electric dry batteries and in chemicals.

Approximately one-half of the total U.S. ferromanganese output is from electric submerged-arc furnaces, and ferromanganese production is usually integrated with silicomanganese production. Annual production of ferromanganese has fallen every year since 1965. Silicomanganese production peaked in 1968 and has since dropped 42 percent. Table IX-2 presents these recent trends. However, with the already evident recovery of the steel industry, the two ferroalloys should display recovery trends in 1972 and 1973.

Over the last few years there has been a slow attrition in the number of U.S. companies and plants. As steel consumption recovers, it is difficult to assess how much of the required ferromanganese and silicomanganese will be provided by domestic production and how much by imports. Several factors account for increasing foreign competition. Low transportation costs are available to foreign producers as many of their plants are located near seaports. A few countries, particularly in northern Europe, have cheap hydroelectric power. As power costs vary from 15 to 40 percent of the manufacturing cost (depending on the product), a cost difference of 4 to 5 mils per kilowatt-hour can amount to $10 to $20 per ton of product, which offers a considerable advantage to the foreign producer.

Tables IX-3 and IX-4 present recent values of both domestic production and imports of ferromanganese and silicomanganese over the last several years. As these tables show, both silicomanganese and ferromanganese are under considerable price pressure.

### b. Calcium Carbide

Calcium carbide, while not related chemically to the ferroalloys, is considered in this study because it is also manufactured in the electric submerged-arc furnace. Over 90 percent of the calcium carbide produced

## Table IX-2. ANNUAL PRODUCTION OF FERROMANGANESE AND SILICOMANGANESE
(short tons)

| Year | Ferromanganese | Silicomanganese |
|---|---|---|
| 1971 | 759,896 | 164,682 |
| 1970 | 835,463 | 193,219 |
| 1969 | 852,019 | 222,877 |
| 1968 | 879,962 | 284,499 |
| 1967 | 940,927 | 245,798 |
| 1966 | 946,210 | 253,134 |
| 1965 | 1,148,011 | 240,667 |
| Growth rate | -5.5% | -6.1% |

Table IX-3. SOURCES AND VALUES OF FERROMANGANESE

| Year | U.S. production,[a] short tons | Value,[b] $/ton | Imports,[a] short tons | Value[c] $/ton |
|---|---|---|---|---|
| 1971 | 759,896 | 168 | 242,778 | 133 |
| 1970 | 835,463 | 167 | 290,946 | 108 |
| 1969 | 852,019 | 143 | 301,956 | 105 |
| 1968 | 879,962 | 159 | 203,212 | 104 |
| 1967 | 940,927 | 147 | 216,279 | 122 |
| 1966 | 946,210 | 148 | 251,972 | 117 |
| 1965 | 1,148,011 | 146 | 257,339 | 122 |

[a] Bureau of Mines, Mineral Yearbook (includes both electric and blast furnace output and all carbon content grades).

[b] Value of shipments without freight or container cost.

[c] Value in foreign port of origin.

Table IX-4. SOURCES AND VALUES OF SILICOMANGANESE

| Year | U.S. production,[a] short tons | Value[b] $/ton | Imports[a] short tons | Value[c] $/ton |
|---|---|---|---|---|
| 1971 | 164,682 | 195 | 29,928 | 132 |
| 1970 | 193,219 | 185 | 14,539 | 122 |
| 1969 | 222,877 | 162 | 32,040 | 110 |
| 1968 | 284,499 | 159 | 25,412 | 105 |
| 1967 | 245,798 | 159 | 34,936 | 118 |
| 1966 | 253,134 | 146 | 35,771 | 117 |
| 1965 | 240,667 | 148 | 17,491 | 109 |

[a] Bureau of Mines, Mineral Yearbook.

[b] Value of shipments without freight or container cost.

[c] Value in foreign port of origin.

domestically comes from Air Reduction Company and Union Carbide Corporation. Other companies producing this chemical are Midwest Carbide (a subsidiary of Chemetron Corporation) in Keokuk, Iowa, and Pryor, Oklahoma, and Pacific Carbide and Alloys in Portland, Oregon.

Table IX-5 presents the recent domestic production, import, and price history of calcium carbide. The import tariff for non-Communist nations is $4.20 per short ton. U.S. production has dipped 43 percent from 1,098,000 tons in 1965 to 625,000 tons in 1971, an annual growth rate of -8.0 percent. Production capacity dropped from 1,195,000 tons in 1955 to 963,000 tons in 1970.[31]

The greatest use for calcium carbide is in the manufacture of acetylene, a major chemical building block. However, it is fast losing ground to acetylene made from petrochemicals.

### c. Ferrochromium

The Ore - Commercial grades of chrome ore, a strategic and critical commodity, are found only in limited areas of the world. North American deposits are of poor quality and cannot compete economically with foreign ores. No chromite ore has been mined in the United States since 1961, when a small amount was produced under the Government Defense Production Act. The world's largest deposits are found in the Transvaal area in the Republic of South Africa. Other major ore deposits are located in Rhodesia, the U.S.S.R., and Turkey. As detailed in Table IX-6, the United States must import all of its chromite needs. As specified in Tariff Classification 601.15,[*] no rate of duty is placed upon chrome ore imports.

Table IX-5. SOURCES AND VALUES OF CALCIUM CARBIDE

| Year | U.S. production,[a] short tons | Value, $/ton | Imports,[b] short tons | Value, $/ton |
|---|---|---|---|---|
| 1971 | 625,000 | 90 | 20,000 | 75 |
| 1970 | 791,000 | 81 | 18,600 | 70 |
| 1969 | 856,000 | 78 | 17,900 | 68 |
| 1968 | 942,000 | 94 | 6,900 | 70 |
| 1967 | 912,000 | 94 | 8,300 | 69 |
| 1966 | 1,063,000 | 87 | 20,200 | 65 |
| 1965 | 1,098,000 | 89 | 10,500 | 70 |

[a] Current Industrial Reports, Department of Commerce, Bureau of the Census.

[b] U.S. Imports for Consumption and General Imports, U.S. Department of Commerce, Bureau of the Census, FT 246 (Calcium Carbide TSUSA 4181400).

Table IX-6. SELECTED STATISTICS ON CHROMITE ORE[3]

| Year | Imports |  |  |  | U.S. consumption |  | U.S. consumer stocks |  |
|---|---|---|---|---|---|---|---|---|
|  | Total, short tons x 1000 | $Cr_2O_3$ content, short tons x 1000 | $Cr_2O_3$ value, $ x 1000 | $Cr_2O_3$ value, $/short ton | All industries, short tons x 1000 | Metals industry, short tons x 1000 | All industries, short tons x 1000 | Metals industry, short tons x 1000 |
| 1970 | 1405 | 647 | 31,805 | 49.16 | 1403 | 912 | 809 | 388 |
| 1969 | 1106 | 506 | 20,030 | 39.58 | 1411 | 898 | 740 | 296 |
| 1968 | 1084 | 499 | 18,189 | 36.45 | 1316 | 804 | 912 | 396 |
| 1967 | 1240 | 568 | 21,854 | 38.48 | 1355 | 866 | 1197 | 459 |
| 1966 | 1864 | 841 | 30,379 | 36.12 | 1461 | 828 | 1306 | 463 |
| 1965 | 1518 | 686 | 25,239 | 36.79 | 1584 | 907 | 1111 | 443 |
| 1964 | 1428 | 646 | 22,713 | 35.16 | 1451 | 832 | 1287 | 509 |
| 1963 | 1391 | 605 | 20,135 | 33.28 | 1187 | 632 | 1583 | 686 |

The chief market for chrome ore is in the manufacture of chrome ferroalloys, with this sector consuming over 60 percent. Other uses include the manufacture of refractory products and the production of bichromates within the chemical industry. Chromite ore has been traditionally classified into three general grades--metallurgical, refractory, and chemical--depending to a large extent upon chromium content, impurities, and the chromium/iron ratio of the deposit. Although the Republic of South Africa accounts for the greatest percentage of U.S. imports, deposits in the Transvaal region are mostly of chemical grade due to the low chrome-iron ratio. Consequently, lesser amounts of ore from this source are used by the ferrochromium industry. Metallurgical-grade ore is normally imported from the U.S.S.R., Rhodesia, and Turkey.

United States consumption of chromite ore has been cyclical, depending upon the domestic market for ferrochromium and the international political situation surrounding ore-exporting nations. From 1960 to 1966 chromite ore imports and ore consumption generally increased at yearly rates of about 5.0 percent and 3.5 percent, respectively. Average ore prices remained relatively stable throughout this period, ranging between $33 and $36 per short ton of chromium content (see Table IX-7). In December 1966, however, the United Nations Security Council passed a resolution calling for an economic boycott of Rhodesia by member nations, declaring that the apartheid policies of that country's government constituted a threat to peace. Pursuant to the U. N. resolution, a Presidential Executive Order was issued in early 1967, imposing sanctions upon trade with Rhodesia. As shown in Table IX-8, which presents import data for metallurgical-grade

Table IX-7. PRICE MOVEMENTS OF CHROMITE ORE[a]

| Country of origin | Chromium content of ore, % | Cr/Fe ratio | December price, $/long ton | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 |
| Rhodesia | 48 | 3:1 | 36.00 | 33.50 | 33.00 | NQ[b] | NQ | NQ | NQ | NQ |
| U.S.S.R. | 54 to 56 | 4:1 | NQ | NQ | 31.75 | 31.75 | 38.25 | 47.20 | 57.20 | 70.00 |
| Turkey | 48 | 3:1 | 37.00 | 31.00 | 30.50 | 33.00 | 35.00 | 38.00 | 48.00 | 55.50 |
| Rep. S. Africa | 44 | 2:1 | 20.25 | 18.50 | 20.25 | 19.75 | 20.25 | 20.25 | 20.25 | 26.00 |

[a] Dry basis subject to penalties if guarantees are not met, F.O.B. cars at Atlantic ports, as quoted in Metals Week.

[b] NQ = not quoted.

Table IX-8. CHROMITE IMPORTS, 46% OR MORE $Cr_2O_3$ CONTENT[3]
(short tons x 1000 unless otherwise specified)

| Country | Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 |
| Rhodesia | 144 | 249 | 244 | 144 | 101 | 0 | 0 | 0 |
| U.S.S.R. | 192 | 275 | 242 | 281 | 299 | 335 | 299 | 407 |
| Turkey | 40 | 38 | 42 | 33 | 44 | 59 | 74 | 135 |
| Rep. S. Africa | 18 | 64 | 115 | 184 | 95 | 92 | 143 | 97 |
| Other | 0 | 25 | 34 | 26 | 0 | 0 | 13 | 62 |
| Total | 394 | 651 | 677 | 669 | 539 | 486 | 529 | 703 |
| $Cr_2O_3$ Content | 193 | 334 | 352 | 348 | 282 | 258 | 276 | 364 |
| Value, $ x 1000 | 7,564 | 12,195 | 12,913 | 13,398 | 11,555 | 9,767 | 11,296 | 20,276 |
| $Cr_2O_3$, $/short ton | 39.19 | 36.51 | 36.68 | 33.50 | 40.98 | 37.86 | 40.93 | 55 70 |

ore, chromite shipments from Rhodesia ceased entirely in 1968. The boycott caused a general decrease in the supply of ore and severe price increases for metallurgical-grade chromite between 1967 and 1971. Although U.S. ore imports diminished during this period, domestic consumption remained relatively constant, causing a general decrease in consumer inventories.

This situation may be alleviated in the near future because in late 1971 the United States Congress passed a military procurement bill containing an amendment that removed Presidential authority to ban imports of Rhodesian chromite after January 1, 1972. The amendment, which forbids embargoes on any strategic material that is also imported from a communist-dominated country, could eventually lead to an improvement in the raw material cost/product price relationships for ferrochromium producers. A small amount of Rhodesian chrome ore entered the United States in 1972; however, political factors have so far prevented normal shipments.

The Product - Ferrochromium is used in various percentages for producing iron castings and all types of steel, with about 70 percent going into stainless steel. Substantial quantities are consumed in the production of superalloys, and small amounts are used in nonferrous alloy production. Output is normally in the forms of HC ferrochromium, LC ferrochromium, or ferrochromium silicon, depending upon the alloy usage and the undesirability of excess carbon as an impurity.

Table IX-9 shows production, shipments, and price statistics for ferrochromium from 1963 to 1970. Although the industry encountered several problems during this period, domestic output of all ferrochromium products

Table IX-9. SELECTED STATISTICS ON FERROCHROMIUM[3]

| Year | HC ferrochromium | | | LC ferrochromium | | | All ferrochromium products,[a] short tons x 1000 | | | Stainless steel, short tons x 1000 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Domestic production, short tons x 1000 | Domestic shipments, short tons x 1000 | Price of contained Cr,[b] $/lb | Domestic production, short tons x 1000 | Domestic shipments, short tons x 1000 | Price of contained Cr,[c] $/lb | Domestic production | Domestic shipments | Imports | Domestic production | Imports |
| 1970 | 172 | 196 | 0.237 | 104 | 101 | 0.315 | 391 | 413 | 41 | 1282 | 177 |
| 1969 | 206 | 210 | 0.201 | 95 | 103 | 0.261 | 433 | 445 | 62 | 1569 | 182 |
| 1968 | 184 | 176 | 0.190 | 90 | 93 | 0.255 | 368 | 365 | 60 | 1432 | 172 |
| 1967 | 201 | 196 | 0.190 | 113 | 110 | 0.255 | 426 | 414 | 58 | 1451 | 149 |
| 1966 | 177 | 181 | 0.190 | 124 | 125 | 0.255 | 416 | 421 | 98 | 1651 | 137 |
| 1965 | 171 | 165 | 0.190 | 134 | 126 | 0.255 | 389 | 374 | 55 | 1493 | 113 |
| 1964 | 159 | 175 | 0.190 | 112 | 127 | 0.255 | 349 | 392 | 26 | 1443 | 79 |
| 1963 | 116 | 115 | 0.240 | 98 | 102 | 0.310 | 300 | 300 | 29 | 1204 | N.A. |

[a] Includes HC and LC ferrochromium, ferrochromium silicon, chromium briquets, chromium metal, and other miscellaneous alloys.

[b] Carloads f.o.b. plant, bulk lump, 67 to 71 percent chromium, quoted in Metals Week as of January.

[c] Maximum carbon content 0.025 percent, carloads, f.o.b. plant, bulk lump, 67 to 73 percent chromium, quoted in Metals Week as of January.

showed rather steady growth. Yearly increases were attained through 1967, after which a cyclical pattern set in for the remainder of the decade. Linear regression shows a growth rate from 1963 to 1970 of approximately 3.2 percent per year, with total domestic production presently about 400,000 short tons per year.

Because of its close relationship with stainless steel (for which market researchers predict long-term growth at a greater rate than for raw steel), ferrochromium should have the most favorable outlook of any of the major ferroalloys. However, three interrelated problems may plague the domestic producers in the near future: (1) Higher chrome ore prices and tightening supplies of metallurgical-grade lump, caused by the Rhodesian boycott, have forced the domestic industry to raise alloy prices. As measured by quotations for LC ferrochromium (maximum carbon content 0.025 percent), prices have increased from 25.5 cents per pound of contained chromium in early 1968 to 39.5 cents per pound in late 1971, a jump of some 55 percent. (2) Such price increases may stimulate higher levels of alloy imports since foreign producers have a cost advantage going into the marketplace. Ferrochromium imports have in fact grown at a rate of about 4.0 percent per year from 1963 to 1970, although the statistics show large fluctuations. Norway, Sweden, and the Republic of South Africa are major suppliers, having easy access to low-cost electric power and/or indigenous raw materials. West Germany, France, and Japan also export substantial quantities to the United States. (3) The rising prices for ferrochromium and nickel have forced parallel increases in quotations for stainless steel, estimated to be costing U.S. consumers an extra $100 million per annum. The domestic steel industry, with mounting competition from abroad, has also lost a substantial part of its stainless steel markets. As shown in Table IX-9, stainless steel imports have risen dramatically from the 1963 level, even with allowance for the programs of voluntary steel import quotas underway since 1969. For 1971, stainless steel imports stood at 191,000 tons, up about 8 percent from the 1970 level.

If international political problems can be settled, the prospects for ferrochromium appear to be favorable. If Rhodesian ore supplies become available once again, the prices for chrome ore should drop and the ore markets should stabilize. Ferrochromium prices should follow a similar downward pattern, which would benefit both alloy producers and the domestic steel industry. Over the long run, growth in demand for ferrochromium should exceed the rate of expansion in steel output, reflecting continued efforts to upgrade certain qualities of steel, particularly corrosion resistance and increased strength. Between 1968 and 2000, the U.S. Bureau of Mines predicts a growth of demand for ferrochromium of 2.0 to 3.3 percent yearly. However, the United States will remain dependent upon foreign sources of chrome ore, a situation that will continue to be a potential problem.

### d. Ferrosilicon

The Ore - Silica raw materials are widely distributed throughout the world, and the processing required to retrieve the ore is relatively simple. United States domestic supplies are plentiful, and the quarrying of quartz, quartzite, and sandstone is essentially a domestic industry. Consequently, ferrosilicon is one of the few ferroalloys made from an ore that is not subject to the fluctuations of international political and economic forces. Conventional processing consists of removing the material with power equipment, followed by crushing, sizing, and washing.

United States production and consumption statistics for silica gravel or crushed rock are not regularly collected. However, with an assumed production ratio of 3 to 1 for quartzite converted to silicon contained in all ferroalloys, the U.S. Bureau of Mines estimated that approximately 1.5 million tons of silica raw materials were quarried in 1968. Because these raw materials are commodities having a low value-to-bulk ratio, transportation costs are a major item and in most cases can determine the source and the distance the material can be hauled. Prices for quartz or quartzite are dependent to a large degree upon chemical analysis, sizing, quantity, and negotiated contracts. For 1968, quoted prices including transportation ranged from $8 to $12 per ton in various locations throughout the nation.

The outlook for silica rock is continued stability. Domestic raw materials will be in ample supply well beyond the year 2000. The United States will not have to depend upon imports for any part of its supply.

The Product - It is estimated that about 90 percent of all silicon is consumed by the iron and steel industry in the form of ferrosilicon alloys. Ferrosilicon is regularly used to deoxidize the molten metal and remove dissolved gases. It is also used to produce high-silicon "alloy" steels with greater corrosion resistance and improved strength, and low-iron-loss steels for electrical transformers and motors. Ferrosilicon is also used in gray iron foundries to increase the amount of silicon in the iron, as it is necessary to add silicon when using scrap steel charge in the cupola. Products are normally classified as silvery pig iron (15 to 20 percent silicon), ferrosilicon (21 to 95 percent silicon), and silicon metal (96 to 99 percent silicon), with several percentage grades made in each class. No silvery pig iron is now made in blast furnaces, but it is produced in the submerged-arc furnace. The major market for silicon metal is the aluminum casting industry. Because iron is unacceptable in aluminum alloys, silicon metal is added to aluminum instead of the normal grades of ferrosilicon to improve corrosion resistance, weldability, and casting and machining properties. Secondary aluminum producers are the largest consumers, accounting for some 65 percent of the demand for silicon metal in 1969.

Table IX-10 gives production, shipments, imports, and price statistics for two classes of ferrosilicon from 1965 to 1971. Based upon simple linear regression, the growth rate for domestic production of silvery pig iron dropped 4.4 percent while that for ferrosilicon rose 3.3 percent per year from 1965 to 1971. Growth in shipments of silvery pig iron, some 85 percent of which is consumed by the gray iron foundry industry, followed the trend in cast iron output from foundries, where production has been slowly receding since 1955. Domestic shipments of 21 to 95 percent ferrosilicon increased about 3.3 percent per year, while prices ranged

Table IX-10. SELECTED STATISTICS ON FERROSILICON[3]

| | Silvery pig iron (5 to 20% Si) | | | Ferrosilicon (21 to 95% Si) | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | Domestic production, short tons x 1000 | Domestic shipments, short tons x 1000 | Value of shipments,[a] ¢/lb Si | Domestic production, short tons x 1000 | Domestic shipments short tons x 1000 | Value of shipments,[a] ¢/lb Si | Net imports, short tons x 1000 | Value of imports,[a] ¢/lb alloy |
| 1971 | 172 | 174 | 25.8 | 687 | 678 | 17.9 | 1[c] | 11.0 |
| 1970 | 196 | 208 | 22.3 | 709 | 659 | 17.5 | 22[c] | 13.3 |
| 1969 | 204 | 204 | 23.4 | 715 | 675 | 14.4 | 27 | 6.8 |
| 1968 | 195 | 216 | 23.4 | 665 | 609 | 14.9 | 7 | 6.4 |
| 1967 | 220 | 210 | 25.9 | 674 | 603 | 14.9 | 19 | 7.3 |
| 1966 | 255 | 246 | 26.6 | 576 | 548 | 16.3 | 25 | 7.6 |
| 1965 | 217 | 224 | 27.0 | 595 | 588 | 15.6 | 12 | 4.9 |

[a] Value of shipments without freight or container costs based on annual average percent silicon of material produced.

[b] Value given in ¢/lb alloy.

[c] 1971 and 1970 figures represent net exports.

from 15 to 18 cents per pound of contained silicon. Markets for ferrosilicon have been growing chiefly because steelmakers have increasingly demanded a wider variety of specialized ferrosilicon grades to be used for high-silicon alloy steels.

As reflected in Table IX-10, imports have not been a major influence upon ferrosilicon markets. Overseas shipments were normally less than inflows until 1970, when exports exceeded imports. Most of the trading is with Canada and the United Kingdom. The Norwegian Ferrosilicon Producers Association announced in 1972 that it has adopted a major marketing program to penetrate the U.S. market.

The outlook for ferrosilicon products is somewhat favorable. Future demands for silvery pig iron and 21 to 95 percent ferrosilicon are expected to follow the trends in iron and steel growth, estimated at 4 percent per year. Because raw materials are plentiful and silica is relatively inexpensive, there is little likelihood that silicon alloys will be replaced by substitute products. Furthermore, technological advances may even increase the use of ferrosilicons for replacement of the more expensive corrosion-resisting additives such as chromium.

### 3. New Units

Concrete projections of the number of new units to be installed by the industry are not readily available in the literature. However, predictions can be made based upon the growth rates of the various product classes and by a consideration of the replacements needed for older furnaces. Although the growth rate for ferromanganese and silicomanganese products has been negative in recent years, consumption should keep pace with the 4 percent annual long-term trend of steel industry growth. However, only 50 percent is currently supplied by electric furnace. If this ratio holds, it will mean a net growth of one 30-mw furnace every 2 years if all the increase can be obtained by domestic producers. However, in the recent past domestic producers have only supplied about 80 percent of the domestic market for ferromanganese and 90 percent of the silicomanganese market.

Generally it is made in the same type of equipment as ferromanganese and silicomanganese. However, no new units are anticipated for the express purpose of producing this material. One source quoted by the Chemical Economics Handbook believes that acetylene derived from calcium carbide may cease to be used for the production of chemicals. The only thing that might reverse this trend would be a jump in the price of the competing light hydrocarbons due to the energy shortage.

Growth rates of approximately 3 percent for ferrochromium and ferrosilicon products seem to dictate that this segment of the industry will need approximately one large furnace (30,000 to 40,000 kw) in alternate years.

There are a total of about 150 existing furnaces in the industry; assuming an average furnace life of 30 years, about five furnaces per year should have to be replaced. The trend in the industry, however, is to replace smaller furnaces (average size estimated to be about 10,000 kw) with much larger units (probably around 40,000 kw). Given a size ratio of 4 to 1 for old-to-new furnaces, it is expected that approximately one unit per year will be needed for replacement purposes. In total, about 5 to 8 new ferroalloy furnaces are estimated to be installed in the next 5 years.

## C. CONTROL COSTS

### 1. Introduction

Capture of pollutants is the critical factor in designing-atmospheric emission control systems for ferroalloy plants. The major source of emissions is the carbon reduction of metallic oxides in the submerged arc furnace. Carbon monoxide is generated continuously along with other reaction gases and fumes. The carbon monoxide from the furnace reaction zone may be withdrawn by an exhaust system without combustion provided a furnace has a closed water-cooled cover and seals around the electrodes. The covered ferroalloy furnace may only be used for a limited number of products but offers the advantage of producting smaller gas volumes to clean than an open, hooded furnace. The small volume of dirty gases from a covered system is typically cleaned by high-energy scrubbers.

The open-furnace system allows induced air to mix with and burn the carbon monoxide above the charge. Depending on design of this particular furnace type, evolution of gases may result in flows of 20 to 50 times those generated by the covered system. The volume of gas flow depends on the hood design, the vertical opening required for stoking the charge, and the diameter of the furnace. In addition, open furnaces with provisions for adding electrode sections under electrical load, require a protection area for electrode installation. Some older open furnaces add electrodes under no load conditions at which time venting occurs directly through roof monitors. To control such a system, hooding requirements call for a much greater volume of gas than would be required if a hood were placed at a lower elevation. Collection devices for open furnaces include fabric filters, scrubbers, and electrostatic precipitators.

In the following sections, costs will be discussed for scrubbers on covered furnaces, and scrubbers and fabric filters on open systems. Not enough data are available to discuss electrostatic precipitator costs. It is important to point out that covered systems work only for a limited number of products--ferromanganese, silicomanganese, 50 percent ferrosilicon, some grades of HC ferrochrome and calcium carbide.

## 2. Model Plants

Model furnaces were developed to evaluate the control cost. Because the trend in the industry is toward larger furnaces than in the past, the size chosen for the models is large - 30 megawatts. Table IX-11 shows the pertinent design parameters associated with the model furnaces. Since silicomanganese (SiMn) can be made in the same furnace interchangeably with high-carbon ferromanganese (HC FeMn), we have assumed that the control equipment for the SiMn furnace will be the same as for the HC FeMn furnace.

## Table IX-11. MODEL FURNACE PARAMETERS

|  | Product |  |  |  |  |
|---|---|---|---|---|---|
| Parameter | HC FeMn | SiMn | 50% FeSi | HC FeCr | $CaC_2$ |
| Power rating, mw | 30 | 30 | 30 | 30 | 30 |
| Product rate,[a] tons/yr. | 99,000 | 44,000 | 47,500 | 51,000 | 91,000 |
| Gas volume from totally enclosed furnace,[b] scfm | 5,000 | 5,000 | 6,000 | 5,000 | 4,000 |
| Gas volume from open furnace,[b] acfm @ 400°F | 350,000 | 350,000[c] | 450,000 | 250,000 | 200,000 |
| Tapping fume gas volume from all furnace types, acfm @ 1500°F[d] | 60,000 | 60,000 | 60,000 | 60,000 | 60,000 |

[a] At 90 percent of full capacity.

[b] The gas volumes represent typical values obtained from the industry survey questionnaires.

[c] Assumed to be the same as for HC FeMn since the furnace may be designed to produce either product.

[d] The figures shown for the tap fume collection are additive to the open furnace volume, based on an open furnace configuration with the collection hood 5 to 7 feet above the furnace deck.

Another emission source that must be controlled besides the furnace itself is the furnace tapping operation. The method of control assumed for this cost analysis depends on the furnace type. For open furnaces the tapping fumes can be collected with a separate hood and vented into the main control device. For other furnaces a separate fabric filter control system would be the most probable method of control.

In addition to the costs for the model plants, costs are presented for a large, totally enclosed furnace that is currently under construction in North America. These data should represent the most up-to-date costs experienced by industry for construction of a totally enclosed furnace in this part of the world.

### 3. Open Furnace Control Costs

Control costs for the model open furnaces shown in Table IX-11 were developed for two types of control devices - fabric filters and wet scrubbers.

a. Fabric Filter Control Costs - Estimates of investment and operating costs required to control open furnaces using fabric filter systems are shown in Table IX-12. These costs were developed from information submitted to EPA by the Industrial Gas Cleaning Institute (IGCI).[32] The tapping fume control system is vented into the fabric filter, and the costs for that system are included. The assumptions that form the basis for these cost estimates will be discussed below. The industry's cost estimates for fabric filter systems are higher than the figures in Table IX-12 because additional equipment and installation factors are considered. The industry's cost estimates are shown in Table IX-13 and will be discussed in the second part of this section.

Table IX-12. CONTROL COSTS FOR FABRIC FILTERS ON OPEN FURNACES

| | Product | | | |
|---|---|---|---|---|
| Cost item | HC FeMn and SiMn | 50% FeSi | HC FeCr | $CaC_2$ |
| Capital cost | | | | |
| Fabric filter | $ 682,000 | $ 832,000 | $ 532,000 | $ 449,000 |
| Auxiliary equipment | 226,000 | 275,000 | 176,000 | 149,000 |
| Installation | 1,142,000 | 1,393,000 | 892,000 | 752,000 |
| Total capital cost | $ 2,050,000 | $ 2,500,000 | $ 1,600,000 | $1,350,000 |
| Annual cost | | | | |
| Operating labor | 53,000 | 53,000 | 53,000 | 53,000 |
| Maintenance (6%) | 123,000 | 150,000 | 96,000 | 81,000 |
| Electricity | 87,000 | 106,000 | 68,000 | 57,000 |
| Capital recovery (15 yr. life, 8% interest) | 240,000 | 292,000 | 187,000 | 158,000 |
| Administration (2%) | 41,000 | 50,000 | 32,000 | 27,000 |
| Taxes and insurance (2%) | 41,000 | 50,000 | 32,000 | 27,000 |
| Total annual cost | $ 585,000 | $ 701,000 | $ 468,000 | $ 403,000 |
| | HC FeMn<br>SiMn | | | |
| Annual cost per ton | $ 5.91<br>$ 13.30 | $ 14.76 | $ 9.18 | $ 4.49 |

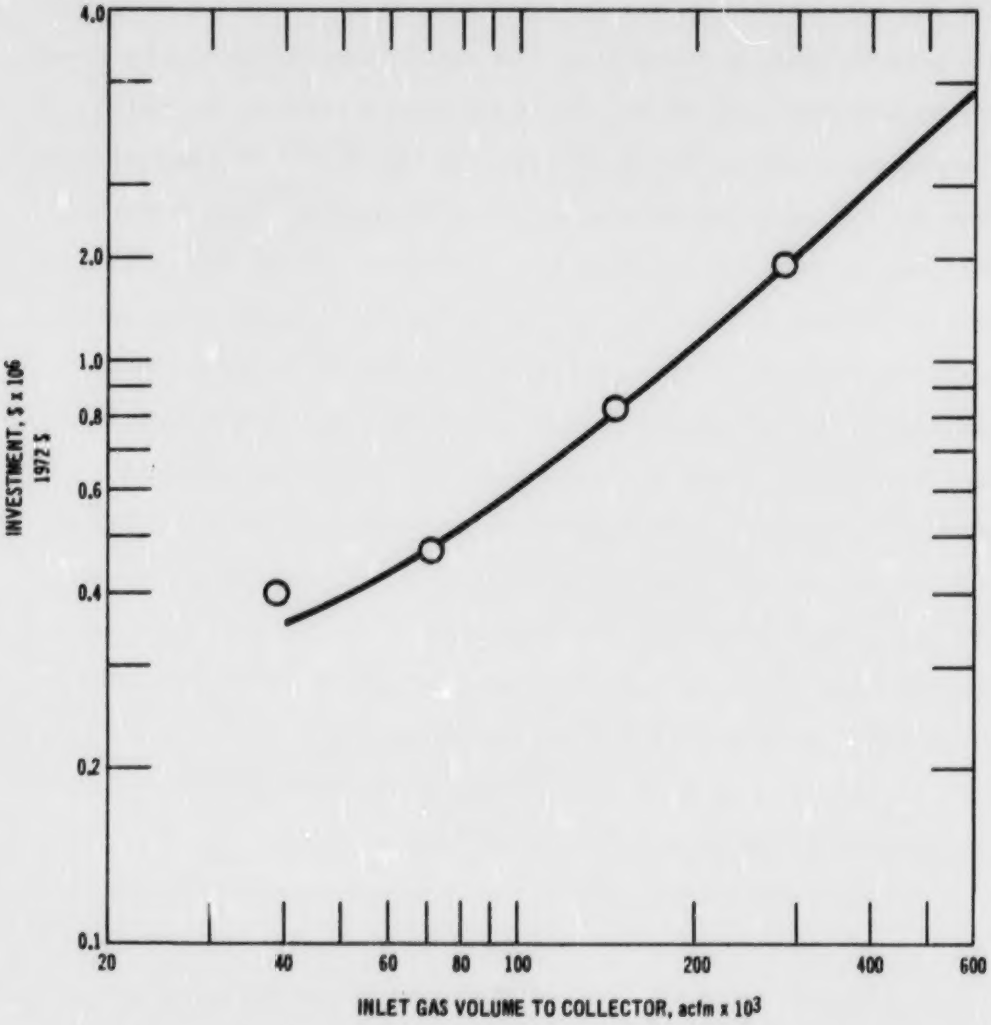

Figure IX-1. Capital costs of open furnace control with fabric filters.[32]

The capital costs for fabric filter installations as received from the IGCI were plotted against the associated collector inlet volumes, and the graph is shown in Figure IX-1. The capital cost for each model furnace may be determined from Figure IX-1 by finding the capital cost that corresponds to the gas volume flow rate for that model. The capital costs from the IGCI study are based on a new plant situation (i.e., a simple duct run, no space limitations, etc.). The costs for the furnace hood and the incremental electrical substation are not included. The capital costs for the fabric filter installations include the baghouse, fans, upstream mechanical collector, dust storage bins with 24-hour capacity, dust hoppers and conveyers, foundation support, ductwork connections, and stack. The charges for engineering design layout, electrical and piping tie-ins, insulation, erection, performance testing, and startup are all included. Fiber glass bags with a temperature resistance of 500°F are assumed to be used. The baghouse is also assumed to contain one extra compartment, which permits shutdown for maintenance.

The following assumptions concerning annual costs of operation apply to operation of the control facility for open furnaces.

1. Replacement parts and maintenance were estimated at 6 percent of the original plant investment for the purpose of replacing 50 percent of the bags and 10 percent of the air valves per annum, and for unknown contingencies.
2. Manpower requirements were estimated to be 1/2 man per shift.
3. Electricity costs account for sufficient power to push the gas into the baghouse with 10 to 12 inches pressure loss for HC FeCr and 15 to 20 inches pressure loss for FeSi. Electrical costs were based on 1 cent per kilowatt-hour.

4. Depreciation and interest charges are accounted for by the use of a capital recovery factor based on 15 year life and on 8 percent interest rate.
5. Administrative costs of 2 percent of original investment and another 2 percent for property tax and insurance were assumed.

The ferroalloy industry has reported higher costs for fabric filter installations due to the following factors:

1. The industry's cost figures are based mainly on installations at existing plant sites. Since these installations must be fit into the available space, certain cost items such as ducting will be more expensive.
2. The industry's figures also include items that were not included in the IGCI cost estimates. These items are the furnace hood cost, electrical substation expansion costs, equipment startup costs, and company engineering and contingency costs.

Including these items and assuming a retrofit installation, the capital costs can be as much as 50 percent higher than the IGCI costs. Table IX-13 shows the industry's cost estimates for the model furnaces.

If the average of the IGCI costs and the industry's costs are used, the annual cost per ton ranges from a low of $5.12 per ton for calcium carbide to $17.73 per ton for 50 percent ferrosilicon.

b. Wet Scrubber Control Costs - Estimates of the investment and operating costs required to control open furnaces using wet scrubbers are shown in Table IX-14. These estimates are derived from information from the Industrial Gas Cleaning Institute (IGCI)[32] and are based on equipment and

Table IX-13. CONTROL COSTS FOR FABRIC FILTERS ON OPEN FURNACES (REPORTED BY INDUSTRY)

| Cost item | HC FeMn and SiMn | 50% FeSi | HC FeCr | $CaC_2$ |
|---|---|---|---|---|
| Capital cost | | | | |
| Fabric filter | $ 1,000,000 | $ 1,265,000 | $ 700,000 | $ 630,000 |
| Auxiliary equipment | 360,000 | 455,000 | 255,000 | 220,000 |
| Installation | 1,640,000 | 2,080,000 | 1,145,000 | 1,050,000 |
| Total capital cost | $ 3,000,000 | $ 3,800,000 | $ 2,100,000 | $ 1,900,000 |
| Annual cost | | | | |
| Operating labor | $ 53,000 | $ 53,000 | $ 53,000 | $ 53,000 |
| Maintenance (6%) | 180,000 | 228,000 | 126,000 | 114,000 |
| Electricity | 87,000 | 106,000 | 68,000 | 57,000 |
| Capital recovery (15 yr. life, 8% interest) | 350,000 | 444,000 | 245,000 | 222,000 |
| Administration (2%) | 60,000 | 76,000 | 42,000 | 38,000 |
| Taxes and insurance (2%) | 60,000 | 76,000 | 42,000 | 38,000 |
| Total annual cost | $ 790,000 | $ 983,000 | $ 576,000 | $ 522,000 |
| | HC FeMn SiMn | | | |
| Annual cost per ton | $ 7.98 $17.95 | $ 20.69 | $ 11.29 | $ 5.74 |

operating requirements to meet the process weight standard published in the Federal Register of August 14, 1971. The costs have been adjusted from IGCI data to reflect the gas flows of the model plants presented in Table IV-11. The costs in Table IX-14 are based on a new plant installation and do not include the furnace hood or additional electrical substation costs. The industry's experience confirms the costs as presented in Table IX-14.

Plots of investment cost data for scrubbers developed by the IGCI are shown in Figure IX-2 for HC ferrochrome and 50 percent ferrosilicon furnaces. The cost curve for ferrochrome was used to develop the costs for all the other alloys except 50 percent ferrosilicon. The investment costs include a venturi scrubber, a fan with at least 20 percent excess capacity, and entrainment separator, aftercoolers, a slurry settler, two filters to dewater the slurry product, and tapping emissions control. The charges for engineering design layout, electrical wiring, piping, insulation, erection, performance testing, and startup are all included. It should be noted that the water treatment equipment may not necessarily be enough to meet EPA's proposed effluent standards.

The annual cost per ton of product ranges from a low of $7.08 per ton for calcium carbide to a high of $34.38 per ton for 50 percent ferrosilicon.

### 4. Totally Enclosed Furnace Control Costs

Capital and annual costs are presented in this section for control devices on totally enclosed furnaces. Since the furnace has a tight cover with seals around the electrodes, the gas volume going to the control device is much smaller than for an open furnace. Thus, the cost of the control

Table IX-14. CONTROL COSTS FOR WET SCRUBBERS ON OPEN FURNACES

| | Product | | | |
|---|---|---|---|---|
| Cost item | HC FeMn and SiMn | 50% FeSi | HC FeCr | $CaC_2$ |
| Capital cost | | | | |
| Scrubber | $ 110,000 | $ 190,000 | $ 96,000 | $ 87,000 |
| Auxiliary equipment | 290,000 | 510,000 | 254,000 | 233,000 |
| Installation | 1,400,000 | 2,450,000 | 1,250,000 | 1,130,000 |
| Total capital cost | $ 1,800,000 | $ 3,150,000 | $ 1,600,000 | $ 1,450,000 |
| Annual cost | | | | |
| Operating labor | $ 26,000 | $ 26,000 | $ 26,000 | $ 26,000 |
| Maintenance (7%) | 126,000 | 220,000 | 112,000 | 102,000 |
| Electricity | 290,000 | 595,000 | 225,000 | 190,000 |
| Water | 155,000 | 298,000 | 118,000 | 99,000 |
| Capital recovery (15 yr. life, 8% interest) | 210,000 | 368,000 | 187,000 | 169,000 |
| Administration (2%) | 36,000 | 63,000 | 32,000 | 29,000 |
| Taxes and insurance (2%) | 36,000 | 63,000 | 32,000 | 29,000 |
| Total annual cost | $ 879,000 | $ 1,633,000 | $ 732,000 | $ 644,000 |
| | HC FeMn SiMn | | | |
| Annual cost per ton of product | $8.88 $19.97 | $34.38 | $14.35 | $ 7.08 |

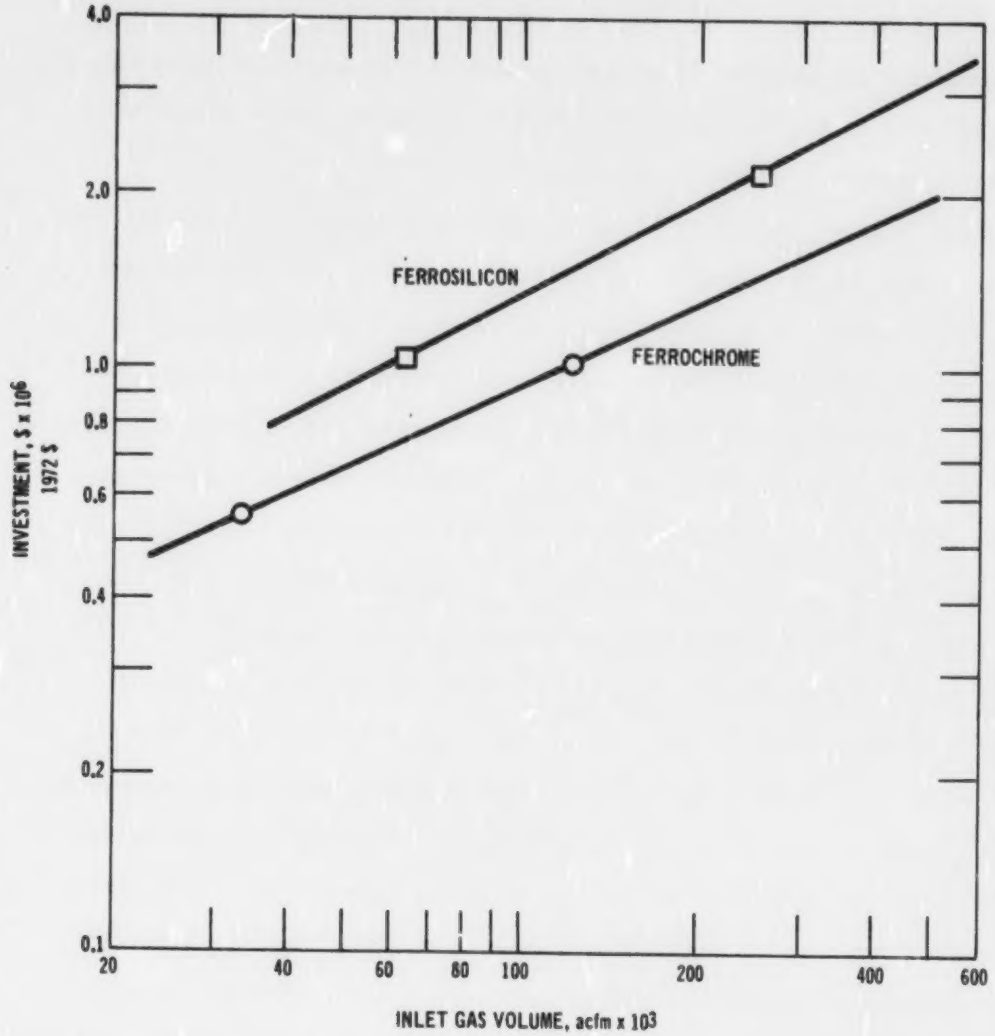

Figure IX-2. Capital costs of open furnace control with wet scrubbers.[32]

device is much smaller than for the open furnace. The higher cost of a covered furnace compared to an open furnace will be discussed in Section 6. In addition to the furnace control device, a separate fabric filter to control taphole emissions is included.

a. Wet Scrubber Control Costs for Furnace Gas Cleaning - The capital and annual cost for two types of wet scrubber control systems are discussed in this section. Both systems are considered best demonstrated technology, but one system includes two parallel control systems which increase the cost. The costs are based on actual costs reported for foreign installations of HC FeMn furnaces updated to 1973 U.S. dollars. However, European construction costs will be generally lower than similar installations in the United States because of differences in building standards, labor rates, safety requirements, accounting procedures, and tax structure.

System A consists of two parallel control devices each capable of handling the total gas flow. The control device is made up of three stages of venturi scrubbers. The draft for this system is provided by aspiration when water is injected at the venturi throats. The capital cost includes the complete scrubber system and the necessary water treatment facilities and flare stack. The annual cost includes operating labor and materials, maintenance, depreciation, interest on capital, administrative costs, property tax and insurance. No credit has been taken for the heat recovery value of the carbon monoxide (CO), which can be a significant amount provided conditions permit use of the gas. For example, the heat value of 5000 scfm of gas (assuming 60 percent CO) from the HC FeMn furnace is about $180,000 per year based on production at 90 percent of full capacity and a heat value of $0.40 per million Btu.

The total reported capital costs for system A was about $630,000, which was about 9 percent of the total furnace installation cost of $7.2 million. The reported annual cost for system A was about $225,000.

System B is another foreign installation consisting of a two-stage venturi scrubber with a fan to supply the necessary pressure. The capital costs include the control system, flare stack, and water treatment facilities.

The reported capital cost of control system B was about $260,000, which was about 6 percent of the total furnace installation cost of 4.5 million. The reported annual cost was about $77,000. Again, no credit has been taken for the heat value of the CO. This furnace was installed at an existing site where some of the existing equipment could be adapted for use with the new furnace.

b. Fabric Filter Control Cost- A few overseas companies use fabric filters as the control device on totally enclosed furnaces. This method of control has not been used in the U.S., and the domestic industry does not expect to use this method of control for totally enclosed furnaces. The estimated capital cost for a conventional fabric filter control system consisting of a radiant cooler, cyclone, fan, fabric filter, dust removal and storage equipment, water seal tank, and flare stack is about $250,000. However, this system would have to be specially designed because of the high concentration of CO gas. These added design considerations could double or triple the cost.

C. Tapping Fume Control Cost- The estimated capital and annual costs presented in Table IX-15 are based on a separate fabric filter control system for emissions generated during the furnace tapping operation. The

Table IX-15. CONTROL COSTS FOR A SEPARATE TAPPING FUME COLLECTION SYSTEM

| Cost item | Cost |
|---|---|
| Capital cost | |
| Fabric filter | $ 85,000 |
| Auxiliary equipment | 55,000 |
| Installation | 260,000 |
| Total capital cost | $ 400,000 |
| Annual cost | |
| Operating labor | $ 10,000 |
| Maintenance (10%) | 40,000 |
| Electricity | 23,000 |
| Capital recovery (15 yr. life at 8% interest) | 47,000 |
| Administration (2%) | 8,000 |
| Taxes and insurance (2%) | 8,000 |
| Total annual cost | $ 136,000 |

assumed flowrate was 60,000 acfm at 150°F. The system includes a hood, fan, fabric filter, and dust removal and storage equipment.

Because the tapping operation can be scheduled with some flexibility, this control system could serve more than one furnace. Possibly two tapping fume hoods could be vented to the same fabric filter, and this would reduce the control cost per furnace. However, for this analysis a separate tapping fume control system for each furnace has been assumed.

### 5. Semi-enclosed Furnace Control Costs

The main difference between a semi-enclosed furnace and a totally enclosed furnace is the method of sealing the area around the electrodes. On the semi-enclosed furnace, the seal is made by maintaining the feed mix around the electrodes. The furnace gases drawn from under the cover require treatment in the same manner as the totally enclosed furnace gas. In addition, hoods may be constructed to capture the emissions that escape around the electrodes. This gas stream can be controlled by combining it with the taphole gases and venting the combined stream to a fabric filter.

One way to illustrate the cost of control for the semi-enclosed furnace is to examine the differences in control cost between the semi-enclosed furnace and the totally enclosed furnace. The capital cost of semi-enclosed furnace installation is lower than the totally enclosed furnace by about the amount of the mechanical seals. On the other hand, electrode and taphole emissions from the semi-enclosed furnace may require a fabric filter that is about twice as large as the fabric filter for the taphole emissions from the totally enclosed furnace. For a 30 mw furnace, the cost of these two factors approximately cancel each other. In general, the control cost for the semi-enclosed furnace is equal to or slightly greater than that for the totally enclosed furnace. The annual cost for the semi-enclosed furnace would be higher by the amount of the operating cost to run the larger fabric filter.

## 6. Case Study of a Totally Enclosed Furnace

As shown by the previous models, the cost of the air pollution control equipment for the totally enclosed furnace is considerably less than the open furnace cost. The main reason is that the gas volume from the totally enclosed furnace is much smaller.

However, the pollution control equipment is not the only consideration when comparing the open and totally enclosed furnace. Actually the open and totally enclosed furnaces require two different sets of process equipment of which the pollution control system is one part.

In order to make a complete comparison of the two furnace types, one should look at the total system from both the process side and the air pollution control side. On one hand the totally enclosed furnace requires a more expensive furnace installation with a larger building, a more complex feed handling system, and a more complex furnace cover. On the other hand, the totally enclosed furnace can be controlled with a much smaller and less expensive air pollution control system. In this section the costs for a totally enclosed furnace are compared to the costs for an open furnace to illustrate this point.

The costs in this section are for a large totally enclosed furnace under construction in North America. These costs should be more representative of the costs that would be experienced at a U. S. location than some of the previously presented costs for totally enclosed furnaces which were based on overseas installations. The maximum power rating for this furnace is 33 mw for HC FeMn and 38 mw for SiMn.

The primary control system for the totally enclosed furnace consists of the sealed furnace cover, a water spray cooler, a mechanical dust separator, and a variable-throat venturi scrubber followed by a mist eliminator. The pressure drop across the scrubber is in the range of 75 to 80 inches of water. The gas flow from the furnace is about 6600 scfm, and the gas flow at the scrubber is about 9700 scfm. The cleaned gas stream, which is high in CO, can be used as a fuel source in the feed pretreatment plant or diverted to a stack. A complete water treatment system is included; the treated water is recycled to the scrubber and the filter cake of solids is recycled to the sintering plant.

The furnace tapping system is designed with a hood over each of four tapholes. A total flow rate of 30,000 acfm is combined with another 20,000 acfm vent stream and sent to a fabric filter collector.

Table IX-16 shows the costs for the totally enclosed furnace and its control equipment compared to the company's estimated costs for an open furnace with a fabric filter collection system. The prorated share of the project's utilities, electrical and engineering expense for the control system is included in the control system cost. In addition to the furnace collection system and the tapping emission collection system, the company reported two other cost factors for the totally enclosed furnace that are different from the open furnace. The first is the incremental furnace cost which includes such items as a more complex feed system, a taller building, and larger and more complex electrode columns and electrical equipment. The second item is an incremental feed pretreatment cost which includes ore and coke dryers and a sinter plant.

## Table IX-16. COMPARISON OF CAPITAL AND ANNUAL COSTS FOR AN OPEN AND A TOTALLY ENCLOSED HC FeMn AND SiMn FURNACE PRODUCING HC FeMn OR SiMn

| Cost item | Open furnace | Totally enclosed furnace |
|---|---|---|
| **Comparison of total capital costs**[a] | | |
| Basic furnace and associated process equipment | $8,500,000 | $ 8,500,000 |
| Incremental furnace cost | -- | 1,400,000 |
| Incremental feed pretreatment | -- | 3,000,000 |
| Air pollution control systems | 3,500,000 | 2,100,000 |
| | $12,000,000 | $15,000,000 |
| **Comparison of control equipment costs** | | |
| **Capital costs**[a] | | |
| Primary system | $ 3,500,000 | $ 1,700,000 |
| Taphole system | (included in above) | 400,000 |
| Incremental furnace cost | -- | 1,400,000 |
| | $ 3,500,000 | $ 3,500,000 |
| **Annual costs** | | |
| Operating cost | $ 143,000 | $ 135,000 |
| Maintenance (6%) | 210,000 | 210,000 |
| Capital recovery (at 8% interest) | 409,000[d] | 390,000[c] |
| Administration (2%) | 70,000 | 70,000 |
| Taxes and insurance (2%) | 70,000 | 70,000 |
| | $ 902,000 | $ 875,000 |
| **Annual cost per ton**[b] **($/ton)** | | |
| HC FeMn | 9.11 | 8.84[e] |
| SiMn | 20.50 | 19.89[e] |

[a] Letter from Mr. D. J. MacIntyre, Manager, Environmental Affairs, Union Carbide Canada Limited. March 9, 1973.

[b] Based on 30 mw for HC FeMn and 34 mw for SiMn, both at 90% operating rate.

[c] Depreciation lives: 10 years - furnace cover, 15 years - pollution control system 20 years - incremental furnace costs.

[d] Depreciation life: 15 years.

[e] This does not include the annualized investment cost or operating cost of the incremental feed pretreatment equipment. The ferroalloy industry has indicated that the total manufacturing cost per ton of product is about equal for both the open furnace with control and the totally enclosed furnace with control and feed preparation.

The decision to use the incremental feed pretreatment must be made after evaluation of the overall process. Drying and sintering allow the use of coke and ore fines and the recovered particulates from the air pollution control systems. Through the use of these feed pretreatment steps the furnace can be operated in a smoother and safer manner. Some foreign plants with totally enclosed furnaces have these additional feed pretreatment steps and some do not. It is even hard to define exactly what should be included as incremental feed pretreatment equipment. For example, some open furnaces have dryers and some do not (depending on the availability of dry materials). Thus, dryers may or may not be considered as incremental equipment for totally enclosed furnaces. The incremental feed pretreatment cost could be considered as part of the air pollution control cost, or could be considered a process addition for which the economics must be justified in each individual case.

In Table IX-16 the capital cost for the incremental feed pretreatment is shown, but these costs are not included in the presentation of the annual cost of the air pollution control equipment. After an overall evaluation was made, this particular plant decided that the totally enclosed furnace with the additional feed pretreatment was the best choice in this case.

It is not possible to generalize from this case to say that in all cases the totally enclosed furnace with feed pretreatment would be the best choice. For example, in the case where a furnace is to be added at an existing plant an open furnace could possibly use the existing feed preparation and delivery system whereas a totally enclosed furnace might require a new, separate feed pretreatment system. Also, the open furnace could possibly be installed in an existing building while the taller, totally enclosed furnace would probably require a new or expanded building. These or other differences at any specific site could affect the costs enough to change the best choice of furnace type to an open furnace.

## D. ECONOMIC IMPACT

### 1. Introduction

The impact of abatement costs will be analyzed in this section, and the model plant approach will be continued through development of income statements before and after control for the five hypothetical plants. The ability of the firm to raise the capital necessary for control will then be discussed. Finally, a general overview of the industry will cover important trends and prospects.

Sufficient data describing the profitability of the ferroalloy industry, particularly with regard to individual products, are difficult to obtain. Three firms that were not diversified have been chosen to represent the industry, so distortion from other product groups is precluded. Table IX-17 presents aggregate operating data for these three firms in terms of percent of sales for the period 1963 to 1971. As can be inferred from the table, operating costs for the 9 years have averaged approximately 93 percent of sales, with earnings before taxes around 7 percent of sales. Net income after taxes has averaged approximately 3.89 percent of sales, and cash flow, about 8.19 percent of sales. These average results will be used to generate model income statments for the five hypothetical plants.

### 2. Model Income Statements

Tables IX-18 and IX-19 present earnings statements for the model plants based on costs presented in Tables IX-12 and IX-13, respectively. Sales figures for ferroalloys were calculated using annual capacities of the 30 mw furnaces and the value per ton of shipments from quotations in the 1973 American Metals Market. These values were: HC ferromanganese, $200.00; silicomanganese, $210.00; HC ferrochrome, $264.00; and 50% ferrosilicon, $175.00. All prices are based on short tons. These sales figures were

Table IX-17. AGGREGATE OPERATING RESULTS FOR THREE REPRESENTATIVE FERROALLOY FIRMS - 1963 to 1971[a],[33]
(percent)

| Item | Year | | | | | | | | | Statistical[c] averages 1963-1971 |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | |
| Sales | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Cost of goods sold, selling, general, and administrative (excluding deprec.) | 94.77 | 90.75 | 84.47 | 83.92 | 88.57 | 90.55 | 87.81 | 86.56 | 87.18 | 88.65 |
| Depreciation and amortization | 4.63 | 3.63 | 3.29 | 3.39 | 4.84 | 4.82 | 4.48 | 4.32 | 5.41 | 4.30 |
| Income tax | 1.66 | 2.15 | 5.49 | 5.61 | 2.80 | 1.68 | 2.64 | 3.52 | 2.83 | 3.16 |
| Net income after tax | - 2.19 | 3.11 | 7.50 | 7.93 | 3.73 | 2.68 | 3.87 | 4.88 | 3.33 | 3.89 |
| Cash flow[b] | 2.16 | 6.74 | 10.79 | 11.33 | 8.57 | 7.50 | 8.35 | 9.20 | 8.75 | 8.19 |

[a] The figures in the table were calculated by (1) summing all items for the firms involved, and (2) calculating the appropriate percentages.

[b] Cash flow was calculated as net income after taxes + depreciation and amortization.

[c] Column entries adjusted to add to 100%.

### Table IX-18. MODEL PLANT INCOME STATEMENTS
($x10^3 unless otherwise indicated)

| Item | Plant description | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | HC FeMn Open furnace Fabric filter | | SiMn Open furnace Fabric filter | | HC FeCr Open furnace Fabric filter | | 50% FeSi Open furnace Fabric filter | |
| Sales[a] | 19,672 | | 9,190 | | 15,550 | | 8,750 | |
| Cost of goods sold and expenses | 17,439 | | 8,147 | | 13,785 | | 7,757 | |
| Depreciation and amortization | 845 | | 395 | | 669 | | 376 | |
| | Before control | After control | Before control | After control | Before control | After control | Before control | After control |
| Annual control costs[b] | -- | 585 | -- | 585 | -- | 468 | -- | 701 |
| Operating income | 1,388 | 803 | 648 | 63 | 1,096 | 628 | 617 | (84) |
| Taxes @45% of operating income | 625 | 361 | 270 | 28 | 493 | 283 | 278 | (38) |
| Net income | 763 | 442 | 378 | 35 | 603 | 345 | 339 | (46) |
| Cash flow[c] | 1,608 | 1,287 | 773 | 430 | 1,272 | 1,014 | 715 | 330 |
| Net income, % sales | 3.88 | 2.25 | 4.11 | 0.38 | 3.88 | 2.22 | 3.87 | (0.53) |
| Net income, $/ton of product | 6.54 | 4.49 | 8.64 | 0.80 | 10.24 | 5.86 | 6.78 | (0.92) |
| Cash flow, $/ton of product | 16.35 | 13.08 | 17.66 | 9.83 | 21.60 | 17.22 | 14.30 | 6.60 |
| Reduction in net income, % | -- | 42.1 | -- | 90.7 | -- | 42.8 | -- | 113.6 |
| Reduction in cash flow, % | -- | 20.0 | -- | 44.4 | -- | 20.3 | -- | 53.8 |

[a] Sales based on following shipments: HC FeM, 98,360 short tons @$200.00; SiMn, 43,760 short tons @$210.00; HC FeCr, 58,900 short tons, @$264.00; and 50% FeSi, 50,000 short tons @$175.00.

[b] Costs from Table IX-12.

[c] Includes 15-year depreciation attributable to control equipment.

## Table IX-19. MODEL PLANT INCOME STATEMENTS
($x$10^3$ unless otherwise indicated)

| Item | Plant description | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | HC FeMn<br>Open furnace<br>Fabric filter | | SiMn<br>Open furnace<br>Fabric filter | | HC FeCr<br>Open furnace<br>Fabric filter | | 50% FeSi<br>Open furnace<br>Fabric filter | |
| Sales[a] | 19,672 | | 9,190 | | 15,550 | | 8,750 | |
| Cost of goods sold and expenses | 17,439 | | 8,147 | | 13,785 | | 7,757 | |
| Depreciation and amortization | 845 | | 395 | | 669 | | 376 | |
| | Before control | After control | Before control | After control | Before control | After control | Before control | After control |
| Annual control costs[b] | -- | 790 | -- | 790 | -- | 576 | -- | 983 |
| Operating income | 1,388 | 598 | 648 | (142) | 1,096 | 520 | 617 | (366) |
| Taxes @45% of operating income | 625 | 269 | 292 | (64) | 493 | 234 | 278 | (165) |
| Net income | 763 | 329 | 356 | (78) | 603 | 286 | 339 | (201) |
| Cash flow[c] | 1,608 | 1,174 | 751 | 317 | 1,272 | 955 | 715 | 175 |
| Net income, % sales | 3.88 | 1.67 | 3.87 | (0.85) | 3.88 | 1.84 | 3.87 | (1.14) |
| Net income, $/ton of product | 7.76 | 3.34 | 8.14 | (1.78) | 10.24 | 4.86 | 6.78 | (4.02) |
| Cash flow, $/ton of product | 16.35 | 11.94 | 17.16 | 7.24 | 21.60 | 16.21 | 14.30 | 3.50 |
| Reduction in net income, % | -- | 56.9 | -- | 121.9 | -- | 52.6 | -- | 159.3 |
| Reduction in cash flow, % | -- | 30.0 | -- | 57.8 | -- | 24.9 | -- | 75.5 |

[a] Sales based on following shipments: HC FeM, 98,360 short tons @$200.00; SiMn, 43,760 short tons @$210.00; HC FeCr, 58,900 short tons, @$264.00; and 50% FeSi, 50,000 short tons @$175.00.

[b] Costs from Table IX-12.

[c] Includes 15-year depreciation attributable to control equipment.

then used to derive operating costs and profits based on the historical percentages in Table IX-17. Tables IX-18 and IX-19 then compare the "before" and "after" affect of imposing control costs on the five model plants.

### 3. Economic Impact on Model Plants

As shown in Table IX-18, which is based on the lower costs developed in Table IX-12, control costs in the absence of product price increases will reduce profits and cash flows significantly. Reduction in net earnings after taxes ranges from 42 percent for HC FeMn to 114 percent for 50% FeSi. Similarly, reductions in cash flows (i.e., the sum of depreciation charges and after-tax earnings) range from approximately 20 percent for HC FeMn to 54 percent for 50% FeSi.

However, if the profit figures are based on costs from Table IX-13 which include retrofit expenses and off-site items, the effect is more drastic. In Table IX-19, silicomanganese and 50 percent ferrosilicon show a net loss, while HC FeMn and HC FeCr show 57 percent and 53 percent reductions in net income, respectively. Cash flow reductions range from 25 to 76 percent. Although application of aggregate corporate operating ratios to the calculation of income statements for individual products may distort the results for any or all of these products, the interpretation of this analysis would remain the same with better data; i.e., control costs are significant relative to the thin profit margins and can only be supported by very substantial price increases.

### 4. Economic Impact on the Domestic Ferroalloy Industry

The preceding section concluded that pollution control for the model plants would have to be supported by price increases to maintain even the current low profit margins. In this section, the total economic impact of emission control on the domestic ferroalloy industry is discussed. The ability of the industry to pass control costs along to the user in the form of higher prices is likewise considered.

The better control systems (baghouses and high-energy scrubbers) installed by industry in recent years have average costs for amortization and operation that total $9.30 (1971 dollars) per ton for ferroalloys having relatively favorable dust-removal properties, such as the products used for the models. Control costs for high-silicon alloys, which have difficult dust-removal properties, average $61 per ton of product for recent installations (see Table IX-20). Emission control costs range from 2 to 9 percent of sales for specific ferroalloys.

The ultimate total cost of emission controls to meet state implementation plans is estimated at approximately $30 million per year for the 2 million tons of ferroalloys produced. This estimate is based on a product mix characteristic of recent industry experience and on unit control costs derived from actual plant visits. These data are shown in Table IX-20. Since annual costs run approximately 25 to 28 percent of required capital costs, the ultimate capital costs will approach $120 million.

As of 1971 only about 20 percent of the total production capacity (based on megawatt ratings) can be regarded as well enough controlled to meet the state implementation plans. Such plants must include good hooding enclosure and high collection efficiency of captured pollutants. The amount of particulate emissions from all ferroalloy furnaces has been estimated to be 150,000 tons annually. Installation and operation of the most effective control systems on all furnaces would ultimately decrease

Table IX-20. PERCENTAGE OF PRODUCTION AND CONTROL COSTS

| Product | Portion of production,[a] net tons | Control costs[b] Historical, $/ton | Recent, $/ton | Average total cost, $ |
|---|---|---|---|---|
| HC FeMn | 348,000 | $ 5.00 | $ 8.00 | $ 2,262,000 |
| SiMn | 194,000 | 9.00 | 18.00 | 2,619,000 |
| LC FeMn | 138,000 | 7.15 | 10.00 | 1,183,000 |
| HC FeCr | 148,000 | 6.15 | 12.00 | 1,343,000 |
| LC FeCr | 126,000 | - | - | - |
| FeCrSi | 86,000 | 11.25 | 15.00 | 1,129,000 |
| Up to 30% Si | 124,000 | 8.00 | 16.00 | 1,488,000 |
| 50% FeSi | 494,000 | 10.00 | 20.00 | 7,410,000 |
| 65% FeSi | 26,000 | 10.00 | 20.00 | 390,000 |
| 75% FeSi | 106,000 | 20.00 | 30.00 | 2,650,000 |
| 85-90% FeSi | 10,000 | 61.00 | 61.00 | 610,000 |
| Si Metal | 116,000 | 61.00 | 61.00 | 7,076,000 |
| MgFeSi | 58,000 | 10.00 | 20.00 | 870,000 |
| Ca alloys[c] | 14,000 | 61.00 | 61.00 | 854,000 |
| All other Si | 12,000 | 20.00 | 20.00 | 240,000 |
| Totals | 2,000,000 | - | - | $30,124,000 |

[a] Based on Price Waterhouse Statistical Reporting Program, 1971, adjusted from 1,632,835 net tons to 2,000,000 net tons.

[b] The Ferroalloys Association.

[c] Excluding calcium carbide production.

the estimated emissions to 8,000 to 10,000 tons annually, based on 1971 production.

The domestic ferroalloy industry is faced with serious economic problems in addition to air pollution control. Slackened demand for many of the products, increased competition from foreign ferroalloy producers, rising electrical power and coal costs, and higher wages have combined to reduce profit margins significantly. A large proportion of the industry has shut down in recent years as a result.

Foreign imports, mostly manganese and chromium products, accounted for 19 percent of domestic consumption in 1971. Imports of silicon products, historically on the order of 3 to 5 percent of domestic consumption for this product class, jumped to 10 percent in 1971. Several factors account for increasing foreign competition. Low transportation costs are available to foreign producers, as their plants are located near the seaports. Some countries, particularly in northern Europe, have cheap hydroelectric power. As power costs vary from 15 to 40 percent of the product manufacturing cost, depending upon the product, a cost difference of 4 to 5 mils per kilowatt-hour or greater between U.S. power rates and overseas hydroelectric rates can amount from $10 for HC FeMn to as high as $70 per ton for silicon, which offers a considerable cost advantage to the foreign production.

High-quality metallurgical coal and coke, which are used in significant quantities by the industry, have become expensive in recent years. Of course, foreign producers have been paying higher prices for these coals, too. Increased prices of ores, machinery, and parts have also been important factors in raising manufacturing costs for the domestic industry.

There are also qualitative factors that may contribute to the stagnation of the industry. The expectation of increased costs for emission control, the difference in government policies among various countries toward taxation, subsidy payments for promotion of industrial growth, advances in foreign technology leading to production efficiencies, and different latitudes in various countries with respect to pollution control regulations all cannot be measured adequately in numeric terms, but are postulated as important factors in the economic setting of the industry today.

Of the groups analyzed, only silicon and ferrosilicon manufacturers seem to be in a position to pay for emission control by raising product prices. The quartz used to produce silicon alloys is plentiful domestically,and demand for silicon products, particularly the silicon metals, appears strong, as measured by an expected annual growth rate of 4 to 6 percent. Lastly, imports are still less than 10 percent of the market measured in terms of domestic shipments. Some of the control costs for silicon products could thus probably be passed on to the consumer. However, silicon and ferrosilicon manufacturers are also facing the greatest costs.

Faced with low growth rate in demand by the steel industry for their products and stiff foreign competition, ferromanganese and ferrochrome producers will be forced to absorb most of their emission control costs. Only through increased production efficiency in the form of higher mechanization and larger plants can ferromanganese and ferrochrome producers hope to retain current profit margins and simultaneously absorb control costs. It is likely the smaller and more marginal plants (i.e., those faced with higher power costs, labor problems, and other cost-associated problems) may either shut down in the face of expected air pollution abatement costs, shift to other product lines, install more efficient manufacturing facilities, or build in other countries which have more lenient standards and lower costs.

# X. RECOMMENDED RESEARCH AND DEVELOPMENT PROGRAMS

## A. INTRODUCTION

Previous sections of this cooperative study have evaluated known control technology, control technology now being tested in commercial operations, and the economic effects of using various methods of emission control.

Present knowledge indicates the various known control methods are not each broadly applicable to controlling emissions from the manufacture of all products. Existing controls result in the accumulation of substantial amounts of wastes in the form of either dusts or drained slurries. Without proper disposal, the dry dusts can be entrained by wind, and the drainage from slurries can become a water pollution problem. With the advent of new source performance standards and the increasingly stringent levels of control generally required under the Clean Air Act Amendments of 1970, the problem of handling and disposing of collected dusts can become more acute.

The technology of covered furnaces is applicable to the manufacture of almost all products except some high-silicon ferroalloys. However, the use of covered furnaces for different product lines has been noted to vary to some extent from country to country; in Japan, for example, covered furnaces have been used to produce silicon alloys containing up to 75 percent silicon. A worldwide evaluation should be made of furnace designs, operating techniques, manufacturing limitations and capabilities, control technology, and economic factors. The goal of such an evaluation would be to determine the extent to which covered furnaces can be applied to the manufacture of high-silicon alloys.

## B. RECOMMENDATIONS

The following recommendations are presented for further research and development.

1. Process Modifications
    a. Determine the relationship of the cost of control to particle size of emissions. This might include an investigation of agglomeration techniques by sonic, electrostatic, or other means that would increase particle size and, presumably, decrease costs.
    b. Examine methods that would decrease the rates of furnace exhaust gas to be handled by control devices, since costs normally decrease when the volumes decrease.
    c. Examine the economics of raw materials (ores, coals, etc.) used as ferroalloy charge stocks and their effects on gaseous and particulate emissions. If possible, develop data on the economic feasibility of using raw materials that would result in the lowest quantity of particulate emissions.
2. Applications of Control Techniques
    a. Examine other types of available control techniques and collection systems besides recognized venturi or other liquid scrubbing systems, baghouse filters, and electrostatic precipitators. This would include examination of all available liquid-contacting nozzle-ejector systems for effectiveness, reduction

in costs, and applicability to a broader range of dusts. Examine combination two-stage systems such as electrostatic precipitator treatment preceding a low-pressure venturi scrubber. Examine the possible domestic application of other systems developed outside the United States, such as multistage scrubbers and the charging chute (shaft kiln).

   b. Examine methods for reducing pressure drop across baghouse collectors.

   c. Develop a fiberglass fabric resistant to higher temperatures or find other fabrics more suitable to ferroalloy dust-filtering operations, with emphasis on extended life of the fabric.

   d. Develop a preconditioner additive for electrostatic precipitators that may be more effective than the currently used ammonia.

3. Waste Utilization

   a. Search for new uses of particulates recovered from various product lines and by various recovery methods. Uses for dry, fluffy dusts and the settled-slurry fine particulates should be included in this search. Examine the chemical content and physical form of the recovery products and search for additional uses in agriculture, industry, and other areas not now in evidence. Examine collected materials for other elements of possible economic value.

   b. Examine in greater depth the possibility of preparing, by extrusion or other means, recovered particulate for recycling to the submerged-arc furnace. The problem of possible wind entrainment is particularly severe with dry dusts. Certain positive values, particularly chromium and manganese, are contained in the dusts and might be recovered for use. Although pelletized chromium- and manganese-containing dusts may not be fully acceptable as desirable charge stock, the stockpiling of these dusts in the pelleted form would prevent their becoming entrained by wind. Such stockpiles could be an important source of raw material for furnace feedstock when other supplies are not available.

4. Waste Heat Utilization

   a. Investigate methods for using the sensible heat of reaction gases as well as heat from the combustion of carbon monoxide therein.

   b. Develop methods for achieving greater utilization of the heat produced within the furnace itself, possibly through the use of water walls.

5. Emission Measurements

   a. A much higher volume sampler is needed at the collector outlet to more quickly obtain an adequate weight of particulate. A sampler should be developed that is simple to apply and that will accurately and quickly reflect the results of control measures.

b. Develop continuous-reading monitors of reliable accuracy for hour-to-hour measurements of outlet particulate concentrations.

# APPENDIX A

## Description of EPA Source Tests

All the data compiled by EPA tests are a part of this Appendix. Furnaces A through J were tested in the United States. Furnaces K and L (ferromanganese and silicomanganese) were tested in a plant located in Norway. A brief description of the process and a flow diagram showing test points are included for each plant tested. Results of each individual sample analysis from tests made on these furnaces are shown in Tables A-2 through A-5. The source of the samples shown in these tables is given in Table A-1. The amount of submicron particulate matter in the gas stream flowing either to or from an air pollution control system was obtained from the back half (impinger catch) of the sampling train; this information is presented in Tables A-6 through A-11. Wherever inlets and outlets were tested simultaneously, the percent collection efficiency (impinger catch only) is shown for each furnace tested. These efficiency rates indicate that the three types of control devices (baghouses, scrubbers, and precipitators) used on these furnaces are effective in removing a high percentage of submicron particulates.

Table A-12 shows the actual gas flow rates and temperatures of the furnace gas streams measured during each individual test run.

## FURNACE A

### Ferrochrome Silicon
### (Uncontrolled)

The initial atmospheric emission tests made by the EPA contractor were conducted May 18 to 19, 1971, on an uncontrolled ferrochrome silicon furnace. The furnace has a hood for collecting the furnace fumes, and it was about 100-percent effective in capturing the fumes. Two exhaust ducts connected at opposite sides of the hood are equipped with blowers that discharge the gas into the open atmosphere through two stacks terminating above the building roof. The tap-hole hood was about 95-percent effective in capturing generated tapping fumes. This hood was vented into the uncontrolled furnace exhaust duct. Figure A-1 shows the uncontrolled exhaust system and test points. The charge material to the furnace was a mixture of chrome ores, quartz, coke, and wood chips. The two exhaust stacks were sampled simultaneously for approximately two hours to cover the tapping cycle. Both the EPA train and the ASME particulate train were used for comparison of results. The two tests with the EPA train showed emissions to be 197 pounds per hour (0.14 gr/scf) and 438 pounds per hour (0.32 gr/scf). The higher emissions for the second test were caused by more furance gas blows than normal because one of the two stoking machines broke down. However, the quantity of emissions for

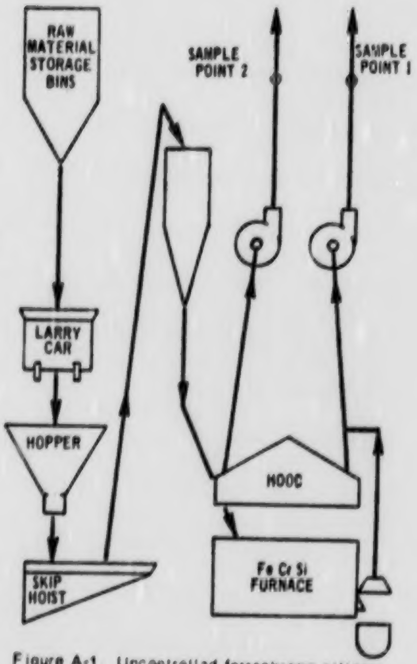

Figure A-1. Uncontrolled ferrochrome silicon furnace both tests was considered lower than normal for this alloy and has been attributed to screened ores used in the furnace mixture. The ASME train showed a slightly higher particulate emission rate than the EPA train (28 percent for the first test and 2 percent for the second test). The percentage of particulates collected in the impingers (back half) of the EPA train was approximately 50 percent during the first day's test at sample point 1 but varied from two to five percent in all other samples. The EPA train was not compared with the ASME train when the high fraction of sample was obtained in the impingers.

The mass media particle size of the fumes emitted varied from 0.62 to 0.67 microns (see Table VI-16 and Appendix D)

Visible emissions ranged from 60 to 100 percent. One of the two stacks serves not only the furnace hood but also the tapping station. Consequently, the larger volumes of gases in this stack dilute the concentration of particulates and results in fewer visible emissions.

Chemical analysis was made of the exhaust gases coming from the furnace and the particulates collected on the filter of the particulate sampling train. Sulfur dioxide ranged from 11 to 17 parts per million. Carbon dioxide and carbon monoxide were 0.8 percent and 0 percent, respectively. Chemical constituents of the collected dust are shown in Table VI-17.

# FURNACE B

## Chrome Ore/Lime Melt Furnace
## (Uncontrolled)

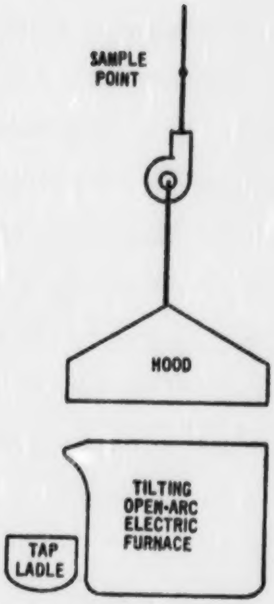

Figure A-2. Uncontrolled chrome ore/lime melt furnace.

On May 20, 1971, a chrome ore/lime melt furnace was tested. Dried and screened chrome ore mixed with lime is charged into an open-arc tilting electric furnace with a pouring spout at the top. The furnace is periodically tilted and the melt falls by gravity into a large ladle, where subsequent ladle reaction with ferrochrome silicon produces a low-carbon ferrochrome (see Flow Diagram, Figure V-3, page V-7). Two test runs were made with results of 50 pounds per hour (0.14 gr/scf) and 61 pounds per hour (0.175 gr/scf). At the same time an ASME sampling train was used with test results of 60.4 pounds per hour and 72.3 pounds per hour. Capture of the fumes by the hooding and exhaust system was judged very poor. With the use of a high-volume filter to determine the particulate concentration and an estimate of the volume of the uncaptured gases escaping the exhaust system, it was shown that emissions escaping the exhaust system varied from 9 to 65 pounds per hour.

Chemical analysis was made of the gases coming from the furnace and the particulates collected on the filter of the particulate sampling train. The analysis showed no sulfur dioxide or carbon monoxide, and only 0.1 percent carbon dioxide. Chemical analysis of the collected particulate sample is shown in Table VI-18.

Particle size was determined by the use of a cascade impactor.

## FURNACE C

### Silicomanganese Furnace
### (Scrubber)

A series of tests were conducted between July 27 and August 4, 1971, on a furnace making silico manganese, 2-percent-carbon grade. The furnace fumes are controlled by two Research Cottrell flooded disc scrubbers discharging into a common stack. Figure A-3 shows the flow diagram of the furnace and scrubber system. Three test runs were made at each scrubber pressure drop setting of 57,47 and 37 inches $H_2O$ pressure. Figure A-4 shows the collection efficiency curves as a result of these tests. The mass emission rates in pounds per hour were 9.8 (0.01 gr/scf), 16.7 (0.02 gr/scf), and 44 (0.05 gr/scf) for pressure drops of 57 inches $H_2O$, 47 inches $H_2O$, and 37 inches $H_2O$, respectively. The percent efficiencies were 99.1 (57 inches $H_2O$), 99.1 (47 inches $H_2O$), and 96.3 (37 inches $H_2O$). The efficiencies were the same for 57 inches $H_2O$ and 47 inches $H_2O$, but the concentration of dust into the scrubber when testing at 47 inches $H_2O$ was 60 percent higher. Even though pressure drop varied across the scrubbers, velocities and temperatures remained relatively constant. The average scrubber inlet particulate loading was 1355 pounds per hour.

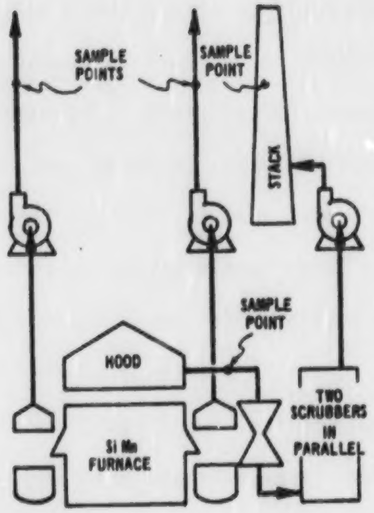

Figure A-3. Scrubber system serving silicomanganese furnace.

Particulate emission rates were also determined for tapping. Tapping time varied for each tapping test from 28 to 32 minutes. There are two tap holes with exhaust systems. but only one tapping station was in use. Therefore, it was necessary to test both stacks simultaneously to obtain the total tapping emissions. Tapping losses for each tapping period were 59 pounds (32 minutes), 27 pounds (30 minutes), and 17 pounds (28 minutes). The average tapping losses (34 pounds) exceed the controlled losses (average over three different pressure drops) by 22 pounds.

Gas analysis made at the scrubber outlet showed sulfur dioxide emission levels generally below 1 ppm. Carbon monoxide was negligible, and carbon dioxide varied between 2 and 3 percent.

The filter catch of the EPA particulate sampling train was analyzed for chemical constituents by use of a microscope, qualitative electron-beam X-ray microanalysis and atomic absorption. The quantities of sample materials were very small, making analysis difficult. The glass fiber of the filter became intermixed with the particulate matter imbedded in the filter, and no accurate silicon analysis could be made. Details concerning the specific elements can be found by referring to Table VI-18.

Several samples were obtained by a cascade impactor to determine particle size. The mass median diameter (MMD) of the particulates at the scrubber exhaust varied from about 0.2 to 0.7 micron. The MMD of particulates from the furnace varied from 0.6 to 5.0 microns. Because of the short sampling time and the varying loading of the gas stream from the furnace outlet, the MMD particle size reported may not reflect a true average particle size from the furnace. However, most of the samples analyzed showed a MMD of less than 1 micron. Table VI-17 and Appendix D shows the particle size of samples collected.

No emissions were visible from the scrubber when it was operated at 57 and 47 inches $H_2O$ pressure drop, but a slight trace of emissions was reported at 37 inches $H_2O$.

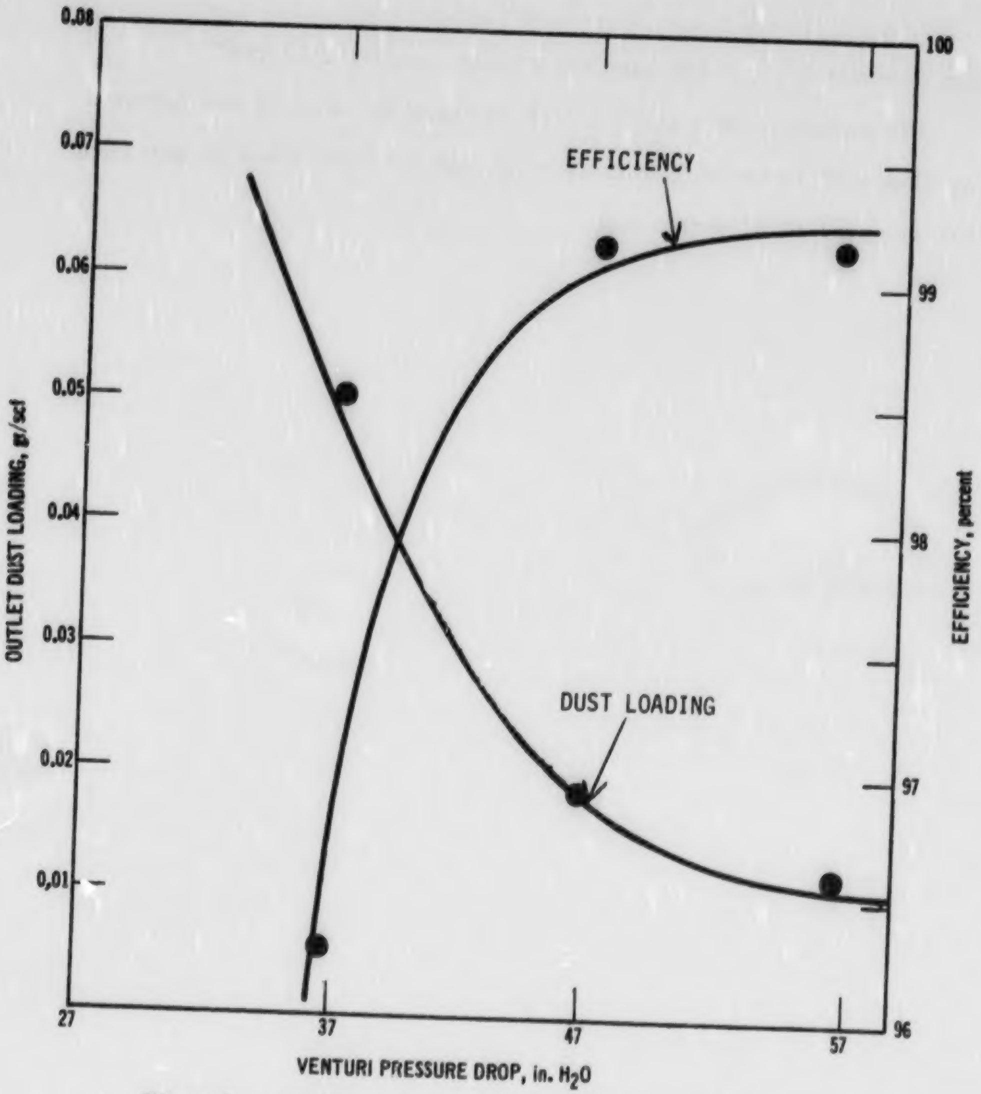

Figure A-4. Scrubber efficiency as function of pressure drop.

## FURNACE D

### Ferrochrome Silicon
### (Baghouse)

Three test runs were made on August 31 to September 1, 1971, on an air pollution control system with a 12-compartment push-through baghouse controlling the fume emissions from a FeCrSi furnace. An air curtain is provided around the periphery of the hood over the furnace with the air provided coming from the exhaust system serving the tapping station hood (see Figure A-5). The larger particle sizes in the exhaust system serving the furnace settle out in the spark arrester. A very small amount settled out in the spark arrester hopper; at the time of the tests, it had not been emptied after several months of operation. The effluent gas stream then passes through two indirect forced draft air coolers, although it had not been necessary to use these as coolers. The dust-laden gas then is directed into a 12-compartment baghouse with a total of 1728 (11-1/2 inch X 30 foot) fiberglass bags. Mechanical shakers clean the bags in each compartment once every 78 minutes.

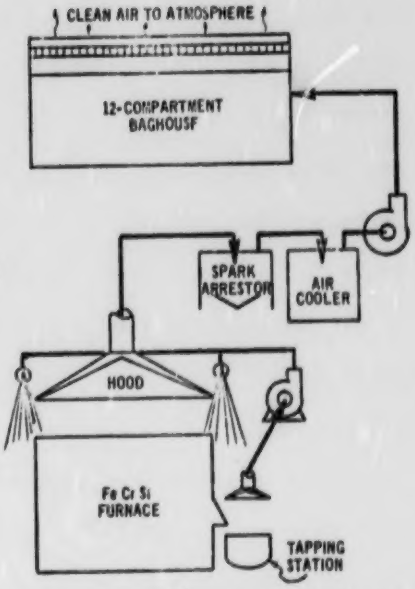

Figure A-5. Baghouse serving ferrochrome silicon furnace.

Three EPA particulate sampling trains were spaced equal distances apart at the baghouse-roof monitor outlet in order to obtain a representative sample. Simultaneous sampling with the three samplers showed that particulate emissions to the atmosphere varied considerably in three test runs, ranging from 18.1 to 37.9 lb/hr with an average of 30 lb/hr. The average grain loading was only 0.009 grains per standard cubic foot. The collection efficiency of the baghouse was 96.5 percent. The percentage of particulates collected in the impinger (back half) of the EPA train was high for an unknown reason and quite consistent for nine samples, ranging only from 63 to 74 percent. The impinger water residue from the sampling train was analyzed by the Sulfaver-Turbidimetric procedure and found to be 33 percent sulfate ion ($SO_4$). Optical emission spectrography has shown most of the material in the water residue to be Fe, Na, Ca, Si, Al, Mg, and K. The sample volume through the sampling train was 88.72 standard cubic feet of dry gas with an $SO_2$ concentration of 0.69 mg/cubic foot. The impinger water thus contained enough $SO_2$ to potentially ionize 91 mg sulfate ion. Total material collected in the impinger weighed 20.4 mg. With the possibility that particulates may have formed from the reactants in the impinger portion, the amount of particulate matter reported going into the atmosphere should be based on the fraction collected in the front half (filter and probe) of the EPA train. In this case, the emissions for the three test runs would be 11.0 lb/hr (0.0035 gr/scf), 9.4 lb/hr (0.0025 gr/scf), and 5.8 lb/hr (0.0014 gr/scf), resulting in a collection efficiency of 98.7%.

Particle size determinations were made by use of a cascade impactor. The mass median diameter (MMD) for the baghouse exhaust was approximately 0.7 to 0.8 microns. The MMD for the furnace exhaust was 0.3 and 3.2 microns during taps and between taps, respectively.

The baghouse exhaust flow rate was too low to measure accurately with a pitot tube. Because air is induced into the baghouse and mixed with the cleaned furnace gases after passing through the cloth filters, it was necessary to measure the induced air by use of a vane anemometer. The volume of gases from the baghouse was determined by adding the measured volume of dirty gases from the furnace going into the baghouse to the measured volume of induced air. Induced air was found to be over half the volume leaving the baghouse. These volumes were verified by use of a heat balance. Another method for determining the amount of dilution air is measuring the concentration of CO into and out of the baghouse. The $CO_2$ readings into and out of the baghouse were 1.2 and 0.5 percent, respectively, which also compared very closely. Including induced air, the baghouse outlet volume was 383,000 SCFM.

The quantity of particulates contained in the air induced into the bottom of the baghouse was determined by use of an ambient air particulate sampler to be 1400 mg/nM$^3$, which means that this concentration of dust was added to the cleaned gases exiting the baghouse. Subtracting the amount of dust in the induced ambient air from the total outlet emissions would only reduce the emissions by slightly less than one pound per hour.

The baghouse was in good operating condition during the tests, and no emissions were visible.

## FURNACE E

### HC Ferrochrome Furnace (Electrostatic Precipitator)

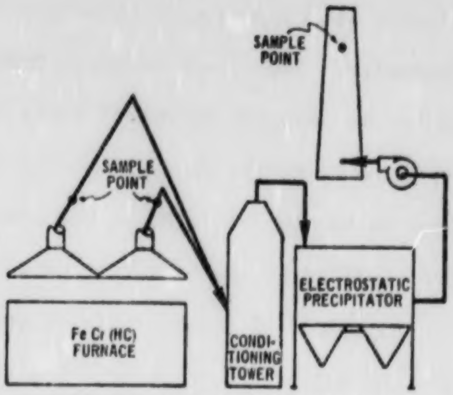

Figure A-6. Electrostatic precipitator serving HC ferrochrome furnace.

Three test runs were made on September 21 to 23, 1971, on a HC ferrochrome furnace equipped with an electrostatic precipitator for controlling furnace fumes. The precipitator is preceded by a gas conditioning tower because of the high resistivity of the ferroalloy fume. The gas conditioner, similar to a scrubber tower in construction, removes approximately 40 percent of the furnace fume. Resistivity of the fumes is reduced by spraying 170 gallons per minute of water into the gas conditioner. Water adsorbing on the dust particles forms a liquid surface film through which electrolytic conduction of the accumulated charge can occur. Since this type of dust does not readily adsorb moisture, a small amount of ammonia is added to enhance the moisture adsorption capacity. The dry precipitator consists of three sections in series with discharge electrodes of negative polarity and positively charged collecting surfaces at ground potential. The furnace hood is equipped with water-cooled, vertically operated doors to minimize the excess air required for effective furnace emission collection. Two tapping holes 120 degrees apart are both vented to the air pollution control system.

The tests showed that the air pollution control system removes 15.4 tons per day of dust and fumes. Average emissions from the precipitator to the atmosphere were 21 pounds per hour with a concentration of 0.0183 grains per standard cubic foot. The average inlet loading to the conditioning tower and precipitator was 1312 lb/hr and 1.87 gr/scf. The collection efficiency was 98.1 percent. The fraction of particulates collected in the water impinger section of the EPA train varied from 8 to 20 percent in the outlet sample and from 0.7 to 3.2 percent in the inlet sample.

Particle size distributions of furnace fumes and precipitator exhaust fumes are shown in Table VI-16 and Appendix D. Average size (mass medium diameter, MMD) of individual particles from the furnace was typically from one to two microns. Frequently, there was little difference between the sizes measured before and following the air pollution control system. The MMD of the fumes at the precipitator outlet varied from 0.38 to 2.54 microns.

Chemical analysis was made of the gas and the filter catch of the sampling train. The average sulfur dioxide analysis from the furnace was 8 ppm. Carbon monoxide varied from 200 to 500 ppm. The percent of carbon dioxide varied from 1.6 to 2.4 percent. The major constituents found on the filter using atomic absorption methods of analysis were found to be Cr, Mg, Al, and $SiO_2$. The major conclusion is that the sample is a mixture of oxides: $SiO_2$, $Cr_2O_3$, MgO, and $Al_2O_3$. The sum of the percent values, after conversion to equivalent oxide values, is 84 percent, which indicates adequate closure in the sense that all the major constituents have been taken into account. The remaining 16 percent could well be accounted for by water of hydration or by the presence of chlorine, carbon, and titanium. Analysis of a dust sample collected by the precipitator unexpectedly found 4.22 percent sodium and 5.95 percent potassium (see Table VI-17).

Chemical analysis made by the company of the collected dust samples showed a difference between the dust collected in the conditioning tower and that collected in the electrostatic precipitator. This is shown in Table A-13. It was speculated the conditioning tower collects the larger dust particles, which are primarily from the mix charge materials, while the electrostatic section collects the fumes from the furnace reactions.

Table A-1 TYPICAL DUST AND FUME ANALYSIS FOR FURNACE E[28]

| Product | Conditioning tower dust, % | Precipitator fume, % |
|---|---|---|
| $Cr_2O_3$ | 28.3 | 5.4 |
| FeO | 7.6 | 6.7 |
| $SiO_2$ | 10.2 | 24.2 |
| $Al_2O_3$ | 25.7 | 7.1 |
| MgO | 15.8 | 38.8 |
| CaO | 3.9 | 12.3 |
| C | 6.0 | 2.3 |

## FURNACE F

### Silicon Furnace
### (Baghouse)

A series of three test runs were conducted on January 17 to 20, 1972, on a three-baghouse system (3744 bags, 11-1/2" diameter X 30' long) serving a silicon furnace. Figure A-7 shows a plan view of this system. Baghouse B was selected for sampling simultaneously with four EPA particulate samplers as the cost would be high to test all three parallel-operated baghouses. The trains were equally spaced in the roof monitor. A representative sample was obtained from all 8 compartments by traversing over the monitor 24 sampling points. The inlet sample was obtained at the furnace outlet exhaust duct. The three tests showed the emissions from Baghouse B only were 11.27, 13.82, and 10.3 pounds per hour. Based on the measured gas flow rates into all three baghouses, and assuming all three baghouses were equally as efficient in particulate removal as Baghouse B, the total amount of emissions to the atmosphere for each test run would calculate to be 28.6, 30.9, and 23.5 pounds per hour. The concentration of particulate emissions to the atmosphere from Baghouse B was 0.006, 0.006, and 0.004 grains per cubic foot. The three baghouses collect 14.6 tons per day

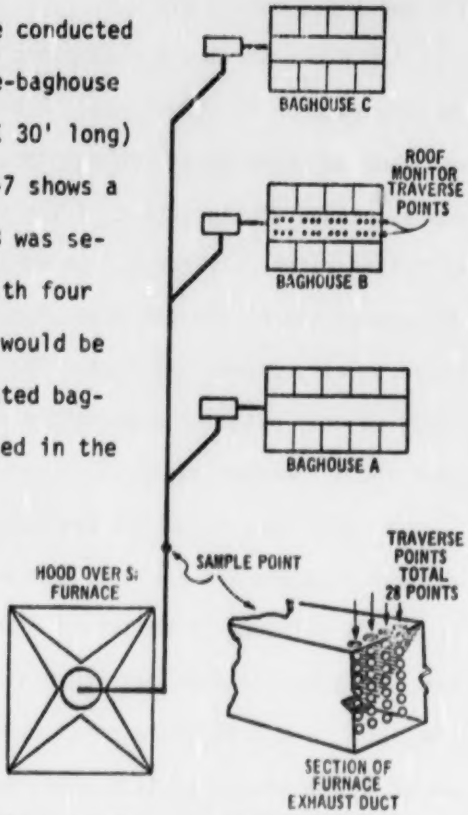
BAGHOUSE C
ROOF MONITOR TRAVERSE POINTS
BAGHOUSE B
BAGHOUSE A
SAMPLE POINT
TRAVERSE POINTS TOTAL 28 POINTS
HOOD OVER Si FURNACE
SECTION OF FURNACE EXHAUST DUCT

Figure A-7. Plan view of baghouse system on silicon furnace.

of particulates from the submerged-arc furnace producing a silicon product. The collection efficiency of the baghouse averaged 98.9 percent for the three test runs.

Two other particulate samplers were used at the baghouse outlet for the purpose of comparison. A Boubel high-volume source test sampler was used adjacent to an EPA sampler, and a high-volume ambient air sampler was suspended at the outlet of the same baghouse compartment. Comparison of filter catch only for all three samplers found the EPA train collected 59 percent and 67 percent more than the Boubel and high-volume samplers respectively, during one test. The other two times, the EPA train was compared only with the high-volume sampler and was found to be 53 percent and 17 percent higher.

An ASME sampler at the baghouse inlet was compared with the EPA sampler, and the EPA train collected 19 percent more particulates based on pounds per hour of emissions. The difference may be attributed to the fact that the ASME testing was started about halfway through the EPA test. The ASME train continued to be used for a sampling period equal to the amount of time that the EPA train was used.

The operating condition of the baghouse sampled appeared good even though there was a small bag leak in one of the end compartments during the first two tests. The results of testing reflect this higher emission. Emissions from the baghouse for test runs one and two were 10 to 35 percent higher than those for test run three. Disregarding the area containing the leaky bag, the baghouse system appeared to be capable of reducing particulate emissions to approximately 0.004 gr/scf or approximately 23 lb/hr.

Laboratory analysis of the 12 outlet samples of particulates from the impinger train (percent of total) varied from 22 to 77 percent and averaged half the total weight.

The plan and side view of the baghouse in Figure A-8 shows where the sampling points were traversed when using four EPA samplers simultaneously. Each sampler determined the quantity of particulate emissions from two baghouse compartments.

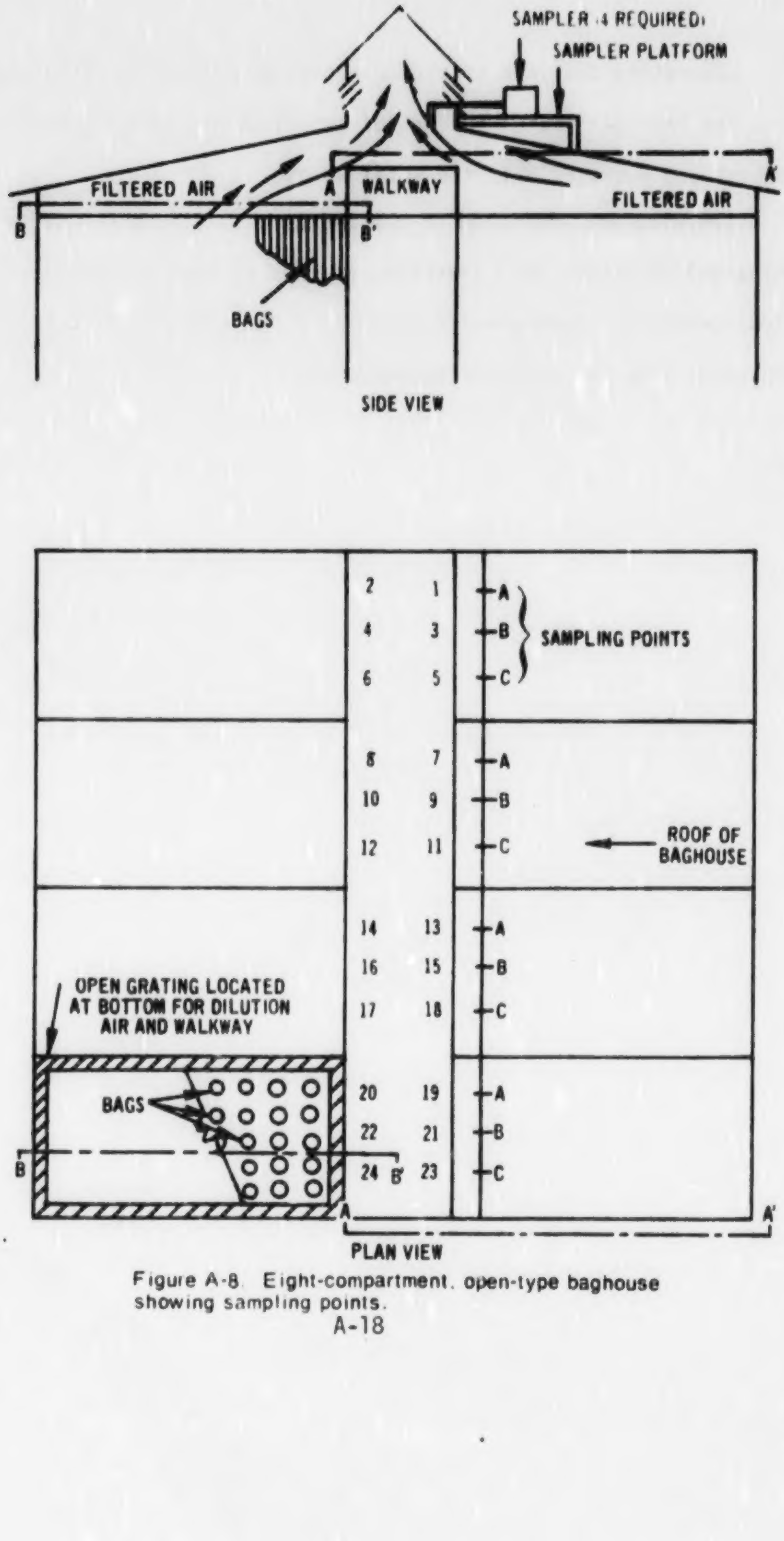
SAMPLER (4 REQUIRED)
SAMPLER PLATFORM
FILTERED AIR
A
WALKWAY
A'
FILTERED AIR
B
B'
BAGS
SIDE VIEW
2
1
A
4
3
B
SAMPLING POINTS
6
5
C
8
7
A
10
9
B
12
11
C
ROOF OF BAGHOUSE
14
13
A
16
15
B
OPEN GRATING LOCATED AT BOTTOM FOR DILUTION AIR AND WALKWAY
17
18
C
BAGS
20
19
A
22
21
B
B
24
B'
23
C
A
A'
PLAN VIEW

Figure A-8. Eight-compartment, open-type baghouse showing sampling points.

## FURNACE G

### SiMn Furnace
### (Scrubber)

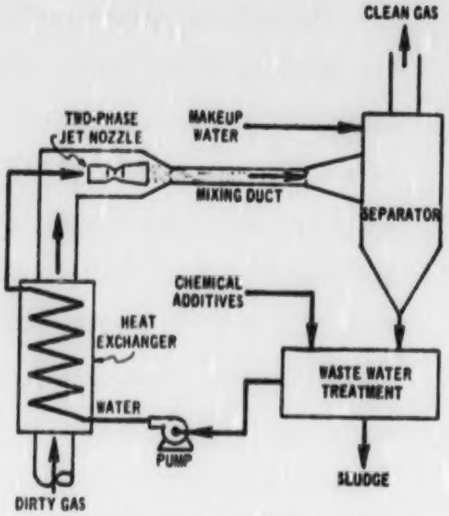

Figure A 9. Aeronetics scrubbing system.

The test conducted on February 1 and 2, 1972, was on an Aeronetics scrubbing system. As dust-laden gas (1100-1200 F) flows from the ferro-alloy furnace, a standard heat-exchanger (see Figure A-8) transfers heat from the gas to high-pressure water that then enters a two-phase jet nozzle. The pressure and temperature of the scrubbing water entering the jet nozzle at a rate of 82 gallons per minute averages 320 pounds per square inch and 375$^{0}$F. A two-phase mixture (steam and water) occurs as the high-pressure heated water passes through the jet nozzle which is located at the inlet of the mixing duct. The mixture thus leaves the nozzle at high velocity, and as it passes through the long venturi section, dust-laden gases are intermixed with the moisture. Concurrently, transfer of momentum of the mixture to the furnace gas stream results in a pressure rise across the mixing section, which produces the force to move the fumes from the furnace into the scrubbing system. The tapping hood is served by an exhaust fan that discharges into the top part of the furnace cover and helps to supply combustion air to the furnace for the conversion of carbon monoxide to carbon dioxide. The conversion process in turn provides heat necessary to drive the scrubber exhaust system. The tapping-hood exhaust system was estimated to be 40-percent effective in capturing tapping fumes.

The emission concentration, including the entire catch of the EPA sampling train, varied from 0.05 to 0.11 grain per standard cubic foot and averaged 0.086 gr/scf. Considering only the front half (probe and filter) of the EPA train, the mass emission rate and concentration varied respectively from 5.8 to 13.6 pounds per hour and from 0.04 to 0.10 gr/scf. The gas cleaning efficiency varied from 92.6 to 97.6 percent. Two of the tests at the control inlet showed lower-than-normal emission factors for this product; the effeciency would thus be correspondingly lower. Particle sizing of the particulates in the scrubber outlet and inlet was obtained during the test by using a Brink cascade impactor. The mass median diameter of the particulate samples varied from 2.41 to 5.1 in the inlet and from 0.18 to 0.50 micron in the stack outlet.

# FURNACE H

## 50% FeSi Furnace
## (Scrubber)

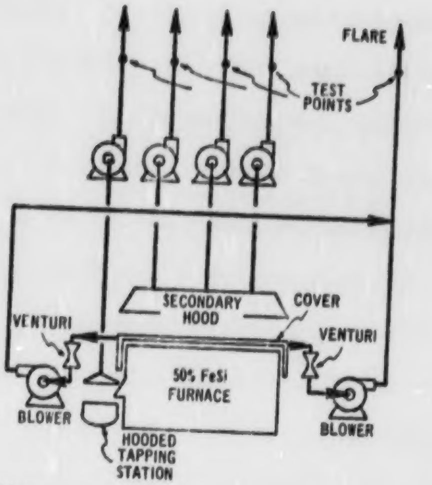

Figure A-10. Covered ferrosilicon furnace with scrubbers.

Tests were made on February 15, 16, and 17, 1972, on a covered 50 percent ferrosilicon furnace served by two parallel-installed Chemico scrubbers operating at 80 to 85 inches $H_2O$ pressure drop. The total volume of furnace exhaust gas is approximately 7000 scfm. Three test runs were made at the sampling point located in the common outlet duct of the two scrubbers. Three test runs were also made in the three outlet ducts of the secondary, uncontrolled exhaust system. The secondary uncontrolled exhaust system captures the fugitive furnace fumes that escapes from the cover and discharges them directly to the atmosphere. Also tested was the uncontrolled tapping station. Figure A-10 shows a schematic diagram of the furnace with the five exhaust stacks and test points. The blowers on the scrubber exhaust were injected with kerosene to prevent binding of the rotors. Any residual kerosene carryover is combusted when flared. All three test runs at the scrubber outlet were of short duration because the filter in the sampling train became quickly loaded. The filter location was changed over to the impinger outlet in the sampling train during test runs 2 and 3 with very little extension of testing time.

The results of the particulate loading in the collected gas before flaring were 86.1, 11.2, and 8.25 pounds per hour. The corresponding grains per standard cubic foot were 0.856, 0.115, and 0.085. Analysis of the filter catch showed a high percentage of combustibles that should have been burned by the flare. When the flare was off, a very distinct emission was visible. No visible emission occurred with the flare on. An attempt was made to determine the inlet loading to the scrubbers by collecting water samples coming out of the scrubbers. The results did not come close to typical inlet loadings for this size furnace; thus the efficiency of the scrubber cannot be precisely determined. However, emission factors indicate that the scrubber is about 98.5 percent efficient, and the efficiency is even higher if the combustibles are not included.

Losses from the secondary hooding varied from 136 to 569 pounds per hour and averaged 342 pounds per hour. Tapping losses averaged 20 pounds per tap. The average tapping time was 15 minutes.

As an experiment, an IKOR sampler was used for comparison of particulate loading during the sampling of the secondary hooding stacks and the tapping stack.[35] This instrument gives instant readout, and it showed wide fluctuation of the particulate loading in the secondary hooding stacks.

Carbon monoxide concentrations appeared stable in the scrubber exhaust but varied considerably in the fugitive fume exhaust ducts, ranging from 50 to 75 ppm with peaks up to 130 ppm.

Because the test of the scrubber outlet was somewhat influenced by kerosene injection into the blower, tests were repeated on July 18 and 19, 1972, without injecting kerosene. Three test runs were made; each lasted approximately one hour. The results were 3.9, 3.6, and 3.6 pounds per hour and on a pounds per megawatt basis were 0.09, 0.08, and 0.07.

# FURNACE J

## Calcium Carbide
## (Scrubber)

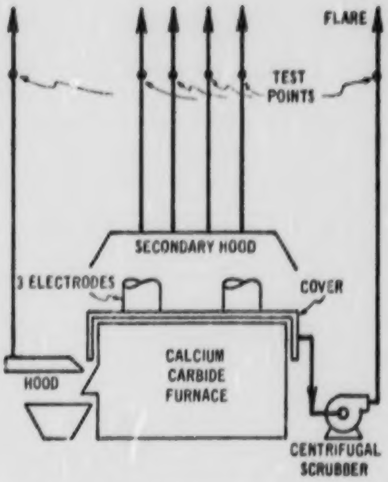

Figure A-11. Covered calcium carbide furnace with scrubber.

Tests were made on February 22, 23, and 24, 1972, on a scrubber outlet stack, four fugitive-fume hood stacks, and a tapping stack all serving a covered calcium carbide furnace. The fume collection system consists of a pair of identical Buffalo Forge (centrifugal) scrubbers, with only one on line and the other one used as a spare. The tapping operation is continuous, and the hood over this area directs all fumes directly to the atmosphere. The molten product pours directly into molds, then is cooled and dumped from the molds in an automatic operation. Figure A-11 shows a schematic diagram of the furnace with the six exhaust stacks and test points.

Three test runs conducted at the scrubber outlet were very consistent and averaged only one-half pound per hour of particulate emissions for the collected gas. The outlet particulate concentration averaged 0.036 grain per standard cubic foot. Fugitive fumes (fumes uncaptured by the scrubber exhaust system) amounted to an average of 58 pounds per hour. The average particulate concentration of these fumes was 0.06 grain/scf. The average tapping particulate emissions of three test runs was 48 pounds per hour with an average concentration of 0.20 grain/scf. Samples of the scrubber effluent water showed that an average of 689 pounds of particulate matter per hour was collected by the scrubber, indicating a scrubber efficiency of 99.9 percent. No solids measurement was taken on the inlet water.

Flue-gas conditions were stable in the scrubber exhaust, but were very erratic and unstable at other locations. Carbon monoxide levels in the fugitive-fume ducts were extremely variable across the area of the traverse; they ranged from 50 ppm to more than 500 ppm. The levels of carbon monoxide in the tapping exhaust were more stable, generally in the range of 35 ppm with occasional peaks up to 150 ppm.

## FURNACE K

### Ferromanganese
### (Scrubber)

This furnace, rated at 27 MW, was tested August 12 to 21, 1972, by EPA personnel in a plant located in Norway. Figure A-12 shows only one scrubber system, but an identical system is located on the opposite side of the furnace. This furnace operating at its rated loading of 27 mw was tested under two conditions, first with only one scrubber system in operation, and then both scrubber systems in operation. The design is based on the use of water jets only, which eliminates need for the exhaust fan found in conventional fan-scrubber systems. The last two stages act as ejectors inducing the movement of gas through the entire exhaust system. The cleaned gas containing a high percentage of carbon monoxide is either flared or sold as a fuel to a nearby chemical plant.

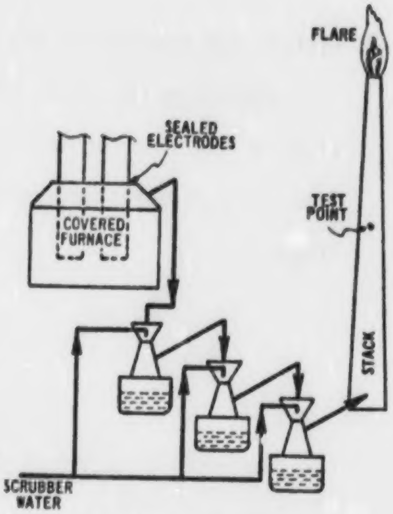

Figure A-12. Covered ferromanganese furnace with sealed electrodes served by three venturis in series.

Six test runs were conducted with only one scrubber system in operation. The concentration of particulates for the collected gas in the scrubber outlet ranged from 0.009 to 0.037 gr/scf and averaged 0.018 gr/scf. The average pounds per megawatt -hour was 0.031.

Two test runs were conducted with both scrubber systems in operation. The concentration of particulates in the scrubber outlet was 0.010 and 0.016 and the average pounds per megawatt -hour was 0.024.

Normally only one scrubber system is used. The company will not install two systems on future furnaces.

Excluding incidents of uncontrolled tapping, no emissions were visible from the furnace except for a few instances during test runs 1 and 2 when emissions were less than 10 percent opacity from fugitive fumes.

## FURNACE L

### Silicomanganese Furnace
### (Scrubber)

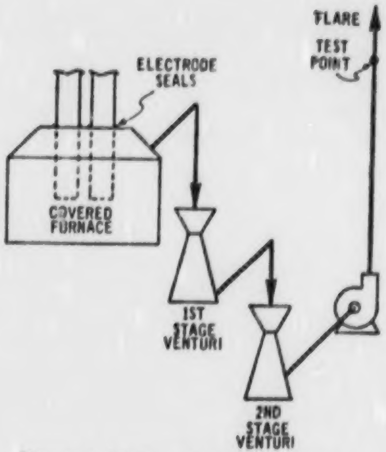

Figure A-13. Covered silicomanganese furnace with sealed electrodes served by two-stage venturi scrubbers.

This covered furnace equipped with sealed electrodes is located in Norway. It is used to make silicomanganese or ferromanganese. During the tests made by EPA personnel on August 23 and 24, 1972, the furnace was making silicomanganese and operating between 22.5 and 23 megawatts. The air pollution control system serving the furnace consists of a two-stage venturi scrubber, two 200-HP exhaust fans, and two 150-HP booster fans. The pressure drop across the first-stage venturi is approximately 2 inches $H_2O$ and across the second stage approximately 50 inches $H_2O$.

Because of operating difficulties in the control system during the fourth test run, data are limited to the first three test runs. The particulate concentration for the collected gas in the scrubber-outlet gas stream ranged from 0.00811 to 0.0113 grain per standard cubic foot and averaged 0.01 gr/scf (probe and filter catch only). On a pound-per-megawatt basis the average emission was 0.009. No emissions were visible from the stack.

Table A-2. KEY TO SAMPLE NUMBERS FOR TABLES A-3 THROUGH A-12

| Furnace | Furnace kilowatts during test | Product | Furnace type | Control equipment | Test point location | Sample number |
|---|---|---|---|---|---|---|
| A | 9,800 | FeCrSi | Open | None | Uncontrolled stack | 1E |
| | | | | | Uncontrolled stack | 1W |
| | 9,300 | | | | Uncontrolled stack | 2E |
| | | | | | Uncontrolled stack | 2W |
| B | 7,200 | Cr ore/ lime melt | Open | None | Uncontrolled stack | 3 |
| | | | | | Uncontrolled stack | |
| C | 29,000 | SiMn | Open | Scrubber | Outlet | 5 |
| | 28,000 | | | | Outlet | 6 |
| | 20,000 | | | | Outlet | 7 |
| | 23,000 | | | | Outlet | 8 |
| | 23,000 | | | | Inlet | 9 |
| | 28,000 | | | | Outlet | 10 |
| | 28,000 | | | | Inlet | 11 |
| | 27,500 | | | | Outlet | 12 (discarded) |
| | 27,500 | | | | Inlet | 13 |
| | 28,000 | | | | Outlet | 14 |
| | 28,000 | | | | Inlet | 15 |
| | 27,500 | | | | Outlet | 16 |
| | 27,500 | | | | Inlet | 17 |

Table A-2 (continued). KEY TO SAMPLE NUMBERS FOR TABLES A-3 THROUGH A-12

| Furnace | Furnace kilowatts during test | Product | Furnace type | Control equipment | Test point location | Sample number |
|---|---|---|---|---|---|---|
| | 27,500 | | | | Outlet | 18 |
| | 27,500 | | | | Inlet | 19 |
| | 28,000 | | | | Outlet | 20 |
| | 28,000 | | | | Inlet | 21 |
| | 27,000 | | | | Outlet | 22 |
| | 27,000 | | | | Inlet | 23 |
| | 27,500 | | | | Outlet | 24 |
| | 27,500 | | | | Inlet | 25 |
| | 28,000 | | | None | Tapping | 26E |
| | 28,000 | | | | Tapping | 26W |
| | 28,000 | | | | Tapping | 27E |
| | 28,000 | | | | Tapping | 27W |
| | 28,000 | | | | Tapping | 28E |
| | 28,000 | | | | Tapping | 28W |
| D | 20,000 | FeCrSi | Open | Baghouse | Outlet | 29N |
| | 20,000 | | | | Outlet | 29C |
| | 20,000 | | | | Outlet | 29S |
| | 20,000 | | | | Inlet | 30 |
| | 22,000 | | | | Outlet | 31N |
| | 22,000 | | | | Outlet | 31C |
| | 22,000 | | | | Outlet | 31S |
| | 22,000 | | | | Inlet | 32 |
| | 20,000 | | | | Outlet | 33N |

Table A-2 (continued). KEY TO SAMPLE NUMBERS FOR TABLES A-3 THROUGH A-12

| Furnace | Furnace kilowatts during test | Product | Furnace type | Control equipment | Test point location | Sample number |
|---|---|---|---|---|---|---|
| E | 20,000 | FeCr (HC) | Open | Precipitator | Outlet | 33C |
| | 20,000 | | | | Outlet | 33S |
| | 20,000 | | | | Inlet | 34 |
| | 32,000 | | | | Outlet | 35 |
| | 33,000 | | | | Inlet | 36E |
| | 33,000 | | | | Inlet | 36W |
| | 34,000 | | | | Outlet | 37 |
| | 34,000 | | | | Inlet | 38E |
| | 34,000 | | | | Inlet | 38W |
| | 33,000 | | | | Outlet | 39 |
| | 34,000 | | | | Inlet | 40E |
| | 34,000 | | | | Inlet | 40W |
| F | | Silicon | Open | Baghouse | Inlet | 41 |
| | | | | | Outlet | 42E |
| | | | | | Outlet | 42EC |
| | | | | | Outlet | 42WC |
| | | | | | Outlet | 42W |
| | | | | | Inlet | 43 |
| | | | | | Outlet | 44E |
| | | | | | Outlet | 44EC |
| | | | | | Outlet | 44WC |
| | | | | | Outlet | 44W |
| | | | | | Inlet | 45 |

Table A-2 (continued). KEY TO SAMPLE NUMBERS FOR TABLES A-3 THROUGH A-12

| Furnace | Furnace kilowatts during test | Product | Furnace type | Control equipment | Test point location | Sample number |
|---|---|---|---|---|---|---|
| | | | | | Inlet | 46 |
| | | | | | Outlet | 47E |
| | | | | | Outlet | 47EC |
| | | | | | Outlet | 47WC |
| | | | | | Outlet | 47W |
| G | 7,800 | SiMn | Open | Scrubber | Inlet | 48 |
| | 7,800 | | | | Outlet | 49 |
| | 7,800 | | | | Inlet | 50 |
| | 7,800 | | | | Outlet | 51 |
| | 7,800 | | | | Inlet | 52 |
| | 7,800 | | | | Outlet | 53 |
| H | 40,500 | FeSi (50%) | Covered | Scrubber | Outlet | 54 |
| | 39,500 | | | | Outlet | 55 |
| | 39,500 | | | | Outlet | 56 |
| | 50,200 | | | None | Fugitive fume Exhaust ducts | 57N |
| | 50,200 | | | | Fugitive fume Exhaust ducts | 57S |
| | 48,700 | | | | Fugitive fume Exhaust ducts | 58N |
| | 48,700 | | | | Fugitive fume Exhaust ducts | 58C |

Table A-2 (continued). KEY TO SAMPLE NUMBERS FOR TABLES A-3 THROUGH A-12

| Furnace | Furnace kilowatts during test | Product | Furnace type | Control equipment | Test point location | Sample number |
|---|---|---|---|---|---|---|
| | 48,700 | | | | Fugitive fume Exhaust ducts | 58S |
| | 52,300 | | | | Fugitive fume Exhaust ducts | 59N |
| | 52,300 | | | | Fugitive fume Exhaust ducts | 59C |
| | 52,300 | | | | Fugitive fume Exhaust ducts | 59S |
| | 50,000 | | | | Fugitive fume Exhaust ducts | 60N |
| | 50,000 | | | | Fugitive fume Exhaust ducts | 60C |
| | 50,000 | | | | Fugitive fume Exhaust ducts | 60S |
| | 40,500 | | | None | Tapping | 61 |
| | 39,500 | | | | Tapping | 62 |
| | 42,000 | | | | Tapping | 63 |
| J | 24,000 | $CaC_2$ | Covered | Scrubber | Outlet | 64 |
| | 23,800 | | | | Outlet | 65 |

Table A-2 (continued). KEY TO SAMPLE NUMBERS FOR TABLES A-3 THROUGH A-12

| Furnace | Furnace kilowatts during test | Product | Furnace type | Control equipment | Test point location | Sample number |
|---|---|---|---|---|---|---|
| | 23,500 | | | | Outlet | 66 |
| | 22,800 | | | None | Fugitive fume Exhaust ducts | 67NE |
| | 22,800 | | | | Fugitive fume Exhaust ducts | 67NW |
| | 22,800 | | | | Fugitive fume Exhaust ducts | 67SW |
| | 23,000 | | | | Fugitive fume Exhaust ducts | 68NE |
| | 23,000 | | | | Fugitive fume Exhaust ducts | 68NW |
| | 23,000 | | | | Fugitive fume Exhaust ducts | 68SE |
| | 23,000 | | | | Fugitive fume Exhaust ducts | 68SW |
| | 21,500 | | | | Fugitive fume Exhaust ducts | 69NE |
| | 21,500 | | | | Fugitive fume Exhaust ducts | 69NW |

Table A-2 (continued). KEY TO SAMPLE NUMBERS FOR TABLES A-3 THROUGH A-12

| Furnace | Furnace kilowatts during test | Product | Furnace type | Control equipment | Test point location | Sample number |
|---|---|---|---|---|---|---|
|  | 21,500 |  |  |  | Fugitive fume Exhaust ducts | 69SE |
|  | 21,500 |  |  |  | Fugitive fume Exhaust ducts | 69SW |
|  | 24,000 |  |  | None | Tapping | 70 |
|  | 23,800 |  |  |  | Tapping | 71 |
|  | 23,800 |  |  |  | Tapping | 72 |

## Table A-3. PARTICULATE EMISSION CONCENTRATIONS AND RATES FROM UNCONTROLLED TEST POINTS

| Furnace | Sample number | Probe and cyclone |  | Probe, cyclone, and filter |  | Impinger |  | Total per sample point (includes water residue) |  | Total from furnace |  | Estimated emissions not captured, percent |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | gr/scf | lb/hr | gr/scf | lb/hr | gr/scf | lb/hr | gr/scf | lb/hr | gr/scf | lb/hr |  |
| A | 1E | 0.052 | 30.1 | 0.220 | 126 | 0.005 | 3 | 0.225 | 129 |  |  |  |
|  | 1W | 0.023 | 18.5 | 0.047 | 37 | 0.040 | 31 | 0.087 | 68 | 0.15 | 197 | 0.5 |
|  | 2E | 0.069 | 42.7 | 0.376 | 232 | 0.012 | 8 | 0.388 | 240 |  |  |  |
|  | 2W | 0.046 | 34.3 | 0.249 | 188 | 0.014 | 10 | 0.263 | 198 | 0.29 | 438 | 0.5 |
| B | 3 | 0.117 | 41.8 | 0.141 | 50 | 0.014 | 5 | 0.154 | 55 | 0.15 | 55 | 53 |
|  | 4 | 0.137 | 47.6 | 0.175 | 61 | 0.003 | 1 | 0.178 | 62 | 0.18 | 62 | 52 |
| C | 9 | 0.180 | 161.0 | 1.05 | 940.4 | 0.01 | 8.9 | 1.06 | 949.3 | 1.06 | 949 | 0.5 |
|  | 11 | 0.386 | 319.0 | 0.423 | 349.8 | 0.04 | 33.9 | 0.464 | 383.7 | 0.46 | 384 | 0.5 |
|  | 13 | 0.98 | 439.0 | 2.22 | 1918.0 | 0.01 | 8.0 | 2.23 | 1926.0 | 2.23 | 1926 | 0.5 |
|  | 15 | 0.98 | 823.0 | 1.92 | 1611.0 | 0.03 | 25.0 | 1.95 | 1636.0 | 1.95 | 1636 | 0.5 |
|  | 17 | 0.99 | 875.0 | 2.10 | 1857.0 | 0.02 | 18.0 | 2.12 | 1875.0 | 2.12 | 1875 | 0.5 |
|  | 19 | 1.25 | 1123.0 | 2.06 | 1846.0 | 0.01 | 10.0 | 2.07 | 1856.0 | 2.07 | 1856 | 0.5 |
|  | 21 | 0.17 | 134.0 | 0.965 | 752.6 | 0.02 | 13.3 | 0.982 | 765.9 | 0.98 | 766 | 0.5 |
|  | 23 | 0.56 | 407.0 | 1.56 | 1209.0 | 0.03 | 22.0 | 1.690 | 1231.0 | 1.69 | 1231 | 0.5 |
|  | 25 | 0.23 | 189.0 | 1.91 | 1553.0 | 0.01 | 9.0 | 1.920 | 1562.0 | 1.92 | 1562 | 0.5 |
| D | 30 | 0.13 | 199.0 | 0.66 | 996.4 | 0.79 | 1194.6 | 1.448 | 2191.0 | 1.45 | 2191[b] | 0.5[b] |
|  | 32 | 0.06 | 81.5 | 0.12 | 173.2 | 0.40 | 583.5 | 0.520 | 756.7 | 0.52 | 757[b] | 0.5[b] |
|  | 34 | 0.06 | 84.7 | 0.40 | 594.4 | 0.59 | 882.9 | 0.990 | 1477.3 | 0.99 | 1477[b] | 0.5[b] |
| E | 36E | 0.48 | 322.0 | 0.892 | 597.0 | 0.03 | 20.0 | 0.922 | 617.0 |  |  |  |
|  | 36W | 0.59 | 415.0 | 1.09 | 761.0 | 0.02 | 16.0 | 1.113 | 777.0 | 1.07 | 1394 | 0.5 |
|  | 38E | 0.40 | 292.0 | 0.819 | 600.0 | 0.01 | 6.0 | 0.827 | 606.0 |  |  |  |
|  | 38W | 0.39 | 253.0 | 0.835 | 538.0 | 0.01 | 6.0 | 0.845 | 544.0 | 0.84 | 1150 | 0.5 |
|  | 40E | 0.43 | 315.0 | 1.107 | 811.0 | 0.01 | 6.0 | 1.114 | 817.0 |  |  |  |
|  | 40W | 0.35 | 253.0 | 0.782 | 573.0 | 0.01 | 5.0 | 0.789 | 578.0 | 0.95 | 1395 | 0.5 |
| F | 41 | 0.085 | 297.0 | 0.815 | 2840.0 | 0.009 | 30.0 | 0.824 | 2870.0 | 0.82 | 2870 | 5 |
|  | 43 | 0.052 | 193.0 | 0.538 | 1980.0 | 0.007 | 30.0 | 0.545 | 2010.0 | 0.55 | 2010 | 5 |
|  | 45 | 0.085 | 286.0 | 0.742 | 2490.0 | 0.004 | 20.0 | 0.746 | 2510.0 | 0.75 | 2510 | 5 |
|  | 46 | 0.078 | 266.0 | 0.723 | 2470.0 | 0.025 | 90.0 | 0.748 | 2560.0 | 0.75 | 2560 | 5 |
| G | 48 | 0.47 | 65.0 | 2.15 | 296.1 | 0.04 | 5.5 | 2.19 | 301.6 | 2.19 | 302 | 2 |
|  | 50 | 0.31 | 43.7 | 1.38 | 194.8 | 0.02 | 2.8 | 1.40 | 197.6 | 1.40 | 198 | 2 |
|  | 52 | 0.42 | 59.5 | 1.33 | 188.1 | 0.02 | 2.8 | 1.35 | 190.9 | 1.35 | 191 | 2 |
| H |  |  |  |  |  |  |  |  |  |  |  | 9[c] |
| J |  |  |  |  |  |  |  |  |  |  |  | 6[c] |

[a] Does not include tapping fume losses unless otherwise indicated.

[b] Includes tapping fume losses.

[c] No inlet samples obtained with EPA sampler. Percent loss based on emission factor and samples obtained of fugitive fume hood.

Table A-4. PARTICULATE EMISSION CONCENTRATIONS AND RATES TO ATMOSPHERE FROM CONTROLLED TEST POINTS

| Furnace | Sample number | Type of control | Probe and filter | | Impinger | | Total per sample point (includes water residue) | | Total into atmosphere | | Efficiency % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | gr/scf | lb/hr | gr/scf | lb/hr | gr/scf | lb/hr | gr/scf | lb/hr | |
| C | 5 | Scrubber 57" PD | 0.010 | 10.0 | 0.007 | 6.1 | 0.017 | 16.1 | 0.02 | 16.1 | |
| | 6 | Scrubber 57" PD | 0.007 | 6.8 | 0.004 | 3.7 | 0.011 | 10.5 | 0.01 | 10.5 | |
| | 7 | Scrubber 57" PD | 0.011 | 11.2 | 0.001 | 1.6 | 0.012 | 12.8 | 0.01 | 12.8 | |
| | 8 | Scrubber 57" PD | 0.008 | 8.1 | 0.002 | 1.6 | 0.010 | 9.7 | 0.01 | 9.7 | 99.0 |
| | 10 | Scrubber 57" PD | 0.009 | 8.4 | 0.002 | 1.5 | 0.011 | 9.9 | 0.01 | 9.9 | 97.5 |
| | 12 | Scrubber 47" PD | Sample | discarded | | | -- | -- | | | |
| | 14 | Scrubber 47" PD | 0.015 | 15.2 | 0.002 | 2.0 | 0.017 | 17.2 | 0.02 | 17.2 | 99.0 |
| | 16 | Scrubber 47" PD | 0.018 | 17.7 | 0.002 | 1.7 | 0.020 | 19.4 | 0.02 | 19.4 | 99.0 |
| | 18 | Scrubber 47" PD | 0.011 | 11.8 | 0.002 | 1.8 | 0.013 | 13.6 | 0.01 | 13.6 | 99.4 |
| | 20 | Scrubber 37" PD | 0.0138 | 13.5 | 0.0006 | 0.6 | 0.0144 | 14.1 | 0.01 | 14.1 | 98.1 |
| | 22 | Scrubber 37" PD | 0.037 | 35.4 | 0.008 | 7.3 | 0.045 | 42.7 | 0.05 | 42.7 | 96.4 |
| | 24 | Scrubber 37" PD | 0.080 | 70.6 | 0.005 | 4.5 | 0.085 | 75.1 | 0.09 | 75.1 | 95.2 |
| D | 29N | Baghouse[a] | 0.0035 | 11.5 | 0.008 | 28.3 | 0.012 | 39.8 | | | |
| | 29C | Baghouse[a] | 0.0042 | 13.8 | 0.010 | 30.5 | 0.014 | 44.3 | 0.01 | 37.9 | 98.0 |
| | 29S | Baghouse[a] | 0.0023 | 7.6 | 0.007 | 21.9 | 0.009 | 29.5 | | | |
| | 31N | Baghouse[a] | 0.0038 | 12.5 | 0.008 | 27.2 | 0.012 | 39.7 | | | |
| | 31C | Baghouse[a] | 0.0028 | 9.2 | 0.007 | 23.0 | 0.010 | 32.2 | 0.01 | 32.5 | 95.0 |
| | 31S | Baghouse[a] | 0.0020 | 6.6 | 0.006 | 19.0 | 0.008 | 25.6 | | | |
| | 33N | Baghouse[a] | 0.0023 | 7.6 | 0.004 | 12.8 | 0.006 | 20.4 | | | |
| | 33C | Baghouse[a] | 0.0014 | 4.6 | 0.004 | 11.5 | 0.005 | 16.1 | 0.005 | 18.1 | 98.9 |
| | 33S | Baghouse[a] | 0.0016 | 5.3 | 0.003 | 12.4 | 0.005 | 17.7 | | | |
| E | 35 | Precipitator | 0.029 | 36.3 | 0.002 | 3.1 | 0.031 | 39.4 | 0.03 | 39.4 | 97.2 |
| | 37 | Precipitator | 0.009 | 12.5 | 0.003 | 3.2 | 0.012 | 15.7 | 0.01 | 15.7 | 98.6 |
| | 39 | Precipitator | 0.010 | 14.2 | 0.003 | 3.0 | 0.013 | 17.2 | 0.01 | 17.2 | 98.8 |
| F | 42E | Baghouse[b] | 0.007 | 4.2 | 0.007 | 2.4 | 0.014 | 6.6 | | | |
| | 42EC | Baghouse[b] | 0.0032 | 1.9 | 0.002 | 0.6 | 0.006 | 2.5 | 0.01 | 11.2 | 99.1 |
| | 42WC | Baghouse[b] | 0.0015 | 0.9 | 0.0005 | 0.2 | 0.002 | 1.1 | | | |
| | 42W | Baghouse[b] | 0.0019 | 0.9 | 0.0001 | 0.1 | 0.002 | 1.0 | | | |
| | 44E | Baghouse[b] | 0.0067 | 5.2 | 0.004 | 1.6 | 0.011 | 6.8 | | | |
| | 44EC | Baghouse[b] | 0.0014 | 1.0 | 0.003 | 1.3 | 0.004 | 2.3 | 0.01 | 13.9 | 98.5 |
| | 44WC | Baghouse[b] | 0.0023 | 1.4 | 0.002 | 1.1 | 0.004 | 2.5 | | | |
| | 44W | Baghouse[b] | 0.0014 | 0.9 | 0.003 | [illegible] | 0.004 | 2.3 | | | |
| | 47E | Baghouse[b] | 0.0026 | 1.5 | 0.001 | 0.6 | 0.004 | 2.1 | | | |
| | 47EC | Baghouse[b] | 0.0018 | 1.1 | 0.004 | 2.4 | 0.006 | 3.5 | 0.01 | 10.2 | 99.1 |
| | 47WC | Baghouse[b] | 0.0017 | 1.0 | 0.002 | 1.3 | 0.004 | 2.3 | | | |
| | 47W | Baghouse[b] | 0.0015 | 0.9 | 0.002 | 1.4 | 0.004 | 2.3 | | | |
| G | 49 | Scrubber | 0.040 | 5.8 | 0.009 | 1.3 | 0.049 | 7.1 | 0.05 | 7.1 | 97.6 |
| | 51 | Scrubber | 0.093 | 12.4 | 0.008 | 1.0 | 0.101 | 13.4 | 0.10 | 13.4 | 93.2 |
| | 53 | Scrubber | 0.102 | 13.6 | 0.005 | 0.6 | 0.107 | 14.2 | 0.11 | 14.2 | 92.6 |
| H | 54 | Scrubber | 0.668 | 67.0 | 0.188 | 19.0 | 0.856 | 86.1 | 0.86 | 86.1 | |
| | 55 | Scrubber | | | | | 0.115 | 11.2 | 0.12 | 11.2 | |
| | 56 | Scrubber | | | | | 0.085 | 8.3 | 0.09 | 8.3 | |
| J | 64 | Scrubber | | | | | 0.043 | 0.6 | 0.04 | 0.6 | |
| | 65 | Scrubber | | | | | 0.031 | 0.4 | 0.03 | 0.4 | |
| | 66 | Scrubber | | | | | 0.034 | 0.5 | 0.03 | 0.5 | |

[a] Three samplers used during each run designated N, C, and S. Total emissions are based on results of each sample. Total for each run is the average of N, C, and S.

[b] Four samplers used during each run designated E, EC, WC, and W. Each sampler covers emissions from two compartments. Total emissions for each test run are the summation of the results of E, EC, WC, and W.

## Table A-5. PARTICULATE LOSSES FROM THE FUGITIVE FUME HOOD[a]

| Furnace | Sample number | Probe and filter | | Impinger | | Total per sample point | | Total into atmosphere | |
|---|---|---|---|---|---|---|---|---|---|
| | | gr/scf | lb/hr | gr/scf | lb/hr | gr/scf | lb/hr | gr/scf | lb/hr |
| H | 57N | 0.095 | 40.6 | 0.008 | 3.6 | 0.103 | 44.2 | 0.11 | 293.0[b] |
| | 57C | Sample rejected - glass probe broke | | | | | | | |
| | 57S | 0.110 | 45.5 | 0.015 | 6.0 | 0.125 | 51.5 | | |
| | 58N | 0.423 | 186.1 | 0.028 | 12.2 | 0.451 | 198.3 | 0.47 | 602.5 |
| | 58C | 0.337 | 157.7 | 0.016 | 7.2 | 0.353 | 164.9 | | |
| | 58S | 0.565 | 225.4 | 0.035 | 13.9 | 0.600 | 239.3 | | |
| | 59N | 0.054 | 22.3 | 0.061 | 25.1 | 0.115 | 47.4 | 0.43 | 516.5 |
| | 59C | 0.358 | 159.9 | 0.064 | 28.6 | 0.422 | 188.5 | | |
| | 59S | 0.740 | 275.5 | 0.014 | 5.1 | 0.754 | 280.6 | | |
| | 60N | 0.078 | 36.0 | 0.033 | 15.5 | 0.111 | 51.5 | 0.13 | 169.1 |
| | 60C | 0.077 | 36.8 | 0.031 | 14.4 | 0.108 | 51.2 | | |
| | 60S | 0.163 | 63.3 | 0.008 | 3.1 | 0.171 | 66.4 | | |
| J | 67NE | 0.161 | 15.8 | 0.003 | 0.4 | 0.164 | 16.2 | 0.09 | 69.0[c] |
| | 67NW | 0.037 | 20.4 | 0.004 | 2.1 | 0.041 | 22.5 | | |
| | 67SE | Sample rejected - glass probe broke | | | | | | | |
| | 67SW | 0.050 | 29.2 | 0.002 | 1.1 | 0.052 | 30.3 | | |
| | 68NE | 0.079 | 8.1 | 0.007 | 0.8 | 0.086 | 8.9 | 0.05 | 64.0 |
| | 68NW | 0.018 | 9.5 | 0.001 | 0.7 | 0.019 | 10.2 | | |
| | 68SE | 0.046 | 13.2 | 0.005 | 1.4 | 0.051 | 14.6 | | |
| | 68SW | 0.029 | 15.7 | 0.015 | 8.5 | 0.044 | 24.2 | | |
| | 69NE | 0.079 | 9.1 | 0.007 | 0.7 | 0.086 | 9.8 | 0.05 | 68.5 |
| | 69NW | 0.021 | 10.8 | 0.003 | 1.7 | 0.024 | 12.5 | | |
| | 69SE | 0.037 | 9.9 | 0.001 | 0.5 | 0.038 | 10.4 | | |
| | 69SW | 0.039 | 20.1 | 0.030 | 15.7 | 0.069 | 35.8 | | |

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[a] Fumes not captured by air pollution scrubber system.

[b] Fugitive fume hood discharges uncontrolled fumes to atmosphere through three stacks. Total into atmosphere is summation of samples N, C, and S. Total of 293 lb/hr would be higher if sample 57C were added.

[c] Fugitive fume hood discharges uncontrolled fumes to atmosphere through four stacks. Total into atmosphere is summation of samples NE, NW, SE, and SW. Total of 69 lb/hr would be higher if sample 67SE were added.

Table A-6. PARTICULATE EMISSION CONCENTRATIONS AND RATES TO ATMOSPHERE FROM TAPPING

| Furnace | Sample number | Probe, cyclone, and filter |  | Impingers |  | Total per sample point |  | Total tapping loss from furnace |  |
|---|---|---|---|---|---|---|---|---|---|
|  |  | gr/scf | lb/tap | gr/scf | lb/tap | gr/scf | lb/tap | gr/scf | lb/tap |
| C | 26E | 0.036 | 11.5 | 0.001 | 0.20 | 0.037 | 11.7 |  |  |
|  | 26W | 0.128 | 37.6 | 0.032 | 9.60 | 0.160 | 47.2 | 0.098 | 58.9[a] |
|  | 27E | 0.025 | 7.5 | 0.003 | 0.80 | 0.028 | 8.3 |  |  |
|  | 27W | 0.048 | 12.8 | 0.022 | 5.60 | 0.070 | 18.4 | 0.049 | 26.7[a] |
|  | 28E | 0.028 | 7.9 | 0.003 | 0.80 | 0.031 | 8.7 |  |  |
|  | 28W | 0.017 | 4.4 | 0.016 | 4.10 | 0.033 | 8.5 | 0.032 | 17.2[a] |
| H | 61 | 0.372 | 28.5 | 0.016 | 0.50 | 0.387 | 29.0 | 0.387 | 29.0 |
|  | 62 | 0.206 | 13.9 | 0.081 | 6.50 | 0.287 | 20.4 | 0.287 | 20.4 |
|  | 63 | 0.347 | 17.9 | 0.004 | 0.20 | 0.351 | 18.1 | 0.351 | 18.1 |
| J | 70 | 0.207 | 52.4[b] | 0.004 | 1.20[b] | 0.211 | 53.6[b] | 0.211 | 53.6[b] |
|  | 71 | 0.190 | 47.2[b] | 0.012 | 3.00[b] | 0.202 | 50.2[b] | 0.202 | 50.2[b] |
|  | 72 | 0.188 | 44.4[b] | 0.003 | 0.80[b] | 0.191 | 45.2[b] | 0.191 | 45.2[b] |

[a] Sum of two tapping stacks serving one tapping station.

[b] Emissions on lb/hr basis (tapping continuous).

### Table A-7. COLLECTION EFFICIENCY ( IMPINGER SECTION ONLY)[a] OF SCRUBBER SERVING FURNACE C

| Scrubber pressure drop, inches $H_2O$ | Sample point | Sample No. | Impinger catch, % | Total particulates, lb/hr | Particulate from impinger section only, lb/hr | Collection efficiency (back half only), % |
|---|---|---|---|---|---|---|
| 57 | Inlet | 9 | 1 | 949 | 9.5 | 83 |
|  | Outlet | 8 | 16 | 9.7 | 1.6 |  |
|  | Inlet | 5 | 9 | 384 | 34.5 | 96 |
|  | Outlet |  | 15 | 9.9 | 1.5 |  |
| 47 | Inlet | 7 | 1.5 | 1636 | 24.5 | 91 |
|  | Outlet |  | 12 | 17.2 | 2.1 |  |
|  | Inlet | 8 | 1 | 1875 | 18.8 | 91 |
|  | Outlet |  | 9 | 19.4 | 1.7 |  |
|  | Inlet | 9 | 0.5 | 1856 | 9.3 | 81 |
|  | Outlet |  | 13 | 13.6 | 1.8 |  |
| 37 | Inlet | 10 | 1.7 | 766 | 13.0 | 95 |
|  | Outlet |  | 4 | 14.1 | 0.6 |  |
|  | Inlet | 11 | 1.8 | 1231 | 22.0 | 68 |
|  | Outlet |  | 17 | 42.7 | 7.2 |  |
|  | Inlet | 12 | 0.5 | 1562 | 7.8 | 42 |
|  | Outlet |  | 6 | 75.1 | 4.5 |  |

[a] Efficiencies shown are calculated from samples collected in the impinger section (back half only) of the EPA sampling train and were based on inlet and outlet samples of the air pollution control device.

Table A-8. COLLECTION EFFICIENCY (IMPINGER SECTION ONLY) OF BAGHOUSE SERVING FURNACE D

| Sample point | Sample no. | Impinger catch,% | Total particulates, lb/hr | Particulates from impinger section only, lb/hr | Collection efficiency (back half only) % |
|---|---|---|---|---|---|
| Inlet | a | 40 | 827[a] | 330 | 92 |
| Outlet | b | 71 | 38[b] | 27 | |
| Inlet | a | 40 | 827[a] | 330 | 93 |
| Outlet | c | 71 | 32.5[c] | 23 | |
| Inlet | a | 40 | 827[a] | 330 | 96 |
| Outlet | d | 68 | 18[d] | 12 | |

[a] Average of samples 30, 32, and 34 obtained on 8-31 and 9-1-71.

[b] Average of samples 29N, 29C, and 29S obtained on 8-31-71.

[c] Average of samples 31N, 31C, and 31S obtained on 9-1-71.

[d] Average of samples 33N, 33C, and 33S obtained on 9-1-71.

Table A-9. COLLECTION EFFICIENCY (IMPINGER SECTION ONLY) OF PRECIPITATOR SERVING FURNACE E

| Sample point | Sample No. | Impinger catch, % | Total particulates, lb/hr | Particulates from impinger section only, lb/hr | Collection efficiency (back half only), % |
|---|---|---|---|---|---|
| Inlet | 36 | 2[a] | 1394 | 27.9 | 89 |
| Outlet | 35 | 8 | 39.4 | 3.1 | |
| Inlet | 38 | 1.0[a] | 1150 | 11.5 | 73 |
| Outlet | 37 | 20 | 15.7 | 3.1 | |
| Inlet | 40 | 0.8 | 1395 | 11.1 | 74 |
| Outlet | 39 | 17 | 17.2 | 2.9 | |

[a] Average of two test points.

Table A-10. COLLECTION EFFICIENCY (IMPINGER SECTION ONLY) OF BAGHOUSE SERVING FURNACE F

| Sample point | Sample No. | Impinger catch, % | Total particulates lb/hr | Particulates from impinger section only, lb/hr | Collection efficiency (back half only), % |
|---|---|---|---|---|---|
| Inlet | 41 | 1.1 | 2870 | 31.6 | 80 |
| Outlet | 42 | 22 | 29 | 6.4 | |
| Inlet | 43 | 1.3 | 2010 | 26.1 | 51 |
| Outlet | 44 | 46 | 28 | 12.9 | |
| Inlet | 46 | 3.4 | 2560 | 87.0 | 86 |
| Outlet | 47 | 54 | 23 | 12.4 | |

Table A-11. COLLECTION EFFICIENCY (IMPINGER SECTION ONLY) OF SCRUBBER SERVING FURNACE G

| Sample point | Sample No. | Impinger catch, % | Total particulates, lb/hr | Particulates from impinger section only, lb/hr | Collection efficiency (back half only), % |
|---|---|---|---|---|---|
| Inlet | 48 | 1.8 | 301.6 | 5.40 | 77 |
| Outlet | 49 | 17.6 | 7.08 | 1.25 | |
| Inlet | 50 | 1.4 | 197.6 | 2.76 | 63 |
| Outlet | 51 | 7.7 | 13.42 | 1.03 | |
| Inlet | 52 | 1.5 | 190.9 | 2.75 | 77 |
| Outlet | 53 | 4.6 | 14.21 | 0.65 | |

Table A-12. PARTICULATE EMISSIONS (IMPINGER SECTION ONLY) FROM FURNACE H[a]

| Run no. | Impinger catch, % | Particulates to atmosphere based total catch, lb/hr | Particulates to atmosphere based on impinger section only, lb/hr | Source of particulates |
|---|---|---|---|---|
| 1 | 8.1 | 44.2 | 3.6 | Mix seals[b] |
|  | 11.6 | 51.5 | 6.0 |  |
| 2 | 6.1 | 198.3 | 12.2 | Mix seals |
|  | 4.3 | 164.9 | 7.2 |  |
|  | 5.8 | 239.3 | 13.9 |  |
| 3 | 52.9 | 47.4 | 25.1 | Mix seals |
|  | 15.1 | 188.5 | 28.6 |  |
|  | 1.8 | 280.6 | 5.1 |  |
| 4 | 30.0 | 51.5 | 15.5 | Mix seals |
|  | 28.1 | 51.25 | 14.4 |  |
|  | 4.7 | 66.4 | 3.1 |  |
| 1 | 4.1 | 105.2 | 4.3 | Tapping |
| 2 | 28.0 | 76.6 | 21.4 | Tapping |
| 3 | 1.3 | 90.7 | 1.1 | Tapping |
| 1 | 22 | 86.1 | 19.0 | Scrubber exhaust |
| 2 | 41 | 11.2[c] | -- |  |
| 3 |  | 8.25[c] | -- |  |

[a] Inlet to scrubber not sampled.

[b] Three exhaust ducts vent mix seal fumes directly to atmosphere.

[c] After run No. 1, filter relocated in test train after silica gel impinger.

## Table A-13. FURNACE GAS VOLUMES

| Product | Average megawatts (test period) | Type of furnace, O-open C-closed | Temperature, °F | Gas volume, acfm |
|---|---|---|---|---|
| FeCrSi | 9.8 | O | 280 | 196,000 |
| FeCrSi | 9.3 | O | 261 | 202,000 |
| Cr ore lime melt | 7.2 | O | 123 | 47,000 |
| Cr ore lime melt | 7.2 | O | 154 | 49,000 |
| SiMn | 23 | O | 599 | 224,000 |
| SiMn | 28 | O | 674 | 203,000 |
| SiMn | 27.5 | O | 607 | 215,000 |
| SiMn | 28 | O | 631 | 216,000 |
| SiMn | 27.5 | O | 633 | 230,000 |
| SiMn | 27.5 | O | 629 | 232,000 |
| SiMn | 28 | O | 655 | 205,000 |
| SiMn | 27 | O | 654 | 199,000 |
| SiMn | 27.5 | O | 541 | 192,000 |
| FeCrSi | 20 | O | 331 | 273,000 |
| FeCrSi | 22 | O | 323 | 271,000 |
| FeCrSi | 20 | O | 336 | 282,000 |
| FeCr (HC) | 33 | O | 460 | 295,000 |
| FeCr (HC) | 34 | O | 470 | 297,000 |
| FeCr (HC) | 34 | O | 445 | 310,000 |
| Si | 17 | O | 300 | 595,000 |
| Si | 17 | O | 300 | 630,000 |
| Si | 17 | O | 310 | 590,000 |
| Si | 17 | O | 307 | 590,000 |
| SiMn | 7.8 | O | 1133 | 51,300 |
| SiMn | 7.8 | O | 1100 | 51,400 |
| SiMn | 7.8 | O | 1106 | 51.700 |
| FeSi (50%) | 42 | C | a | 7,600[b] |
| FeSi (50%) | 41 | C | a | 7,600[b] |
| FeSi (50%) | 45 | C | a | 7,600[b] |
| $CaC_2$ | 24 | C | a | 1,443[b] |
| $CaC_2$ | 23.8 | C | a | 1,443[b] |
| $CaC_2$ | 23.5 | C | a | 1,443[b] |

[a] No. test conducted at inlet.

[b] Volumes (scfm) based on outlet test.

# APPENDIX B

## SAMPLING AND ANALYTICAL TECHNIQUES

The procedures and equipment used by EPA personnel or by contractors working for EPA to measure particulate and other emissions are described in the appendix of the Federal Register, 42CFR Part 466, Proposed Standards of Performance for New Stationary Sources (Vol. 36, No. 159, August 17, 1971). The applicable test methods are reprinted below.

A suitable sampling site and the required number of traverse points were determined according to Method 1. The volumetric flow rate of the total effluent was obtained by using Method 2. For each run, the average concentration of particulate matter was determined by using Method 5. A limited number of tests were also made for the determination of sulfur dioxide by Method 6.

Because of the configuration of ducting at certain sample points, it was sometimes necessary to deviate from the procedures set forth in Method 1. The sampling points in these situations were located in the only possible or usable places, but care was taken that representative samples were nevertheless obtained.

Sample ports and procedures for all tests were approved by the EPA project officer in charge of testing.

FEDERAL REGISTER, VOL. 36, NO. 159—TUESDAY, AUGUST 17, 1971—TEST METHODS

### METHOD 1—SAMPLE AND VELOCITY TRAVERSES FOR STATIONARY SOURCES

1. *Principle and applicability.*

1.1 Principle. A sampling site and the number of traverse points are selected to aid in the extraction of a representative sample.

1.2 Applicability. This method should be applied only when specified by the test procedures for determining compliance with

New Source Performance Standards. This method is not intended to apply to gas streams other than those emitted directly to the atmosphere without further processing.

2. *Procedure.*

2.1 Selection of a sampling site and minimum number of traverse points.

2.1.1 Select a sampling site that is at least eight stack or duct diameters downstream and two diameters upstream from any flow disturbance such as a bend, expansion, contraction, or visible flame. For a rectangular cross section, determine an equivalent diameter from the following equation:

$$\text{equivalent diameter}=2\left[\frac{(\text{length})(\text{width})}{\text{length}+\text{width}}\right]$$

equation 1-1

2.1.2 When the above sampling site criteria can be met, the minimum number of traverse points is twelve (12).

2.1.3 Some sampling situations render the above sampling site criteria impractical. When this is the case, choose a convenient sampling location and use Figure 1-1 to determine the minimum number of traverse points.

2.1.4 To use Figure 1-1 first measure the distance from the chosen sampling location to the nearest upstream and downstream disturbances. Determine the corresponding number of traverse points for each distance from Figure 1-1. Select the higher of the two numbers of traverse points, or a greater value, such that for circular stacks the number is a multiple of four, and for rectangular stacks the number follows the criteria of section 2.2.2.

2.2 Cross sectional layout and location of traverse points.

2.2.1 For circular stacks locate the traverse points on two perpendicular diameters according to Figure 1-2 and Table 1-1.

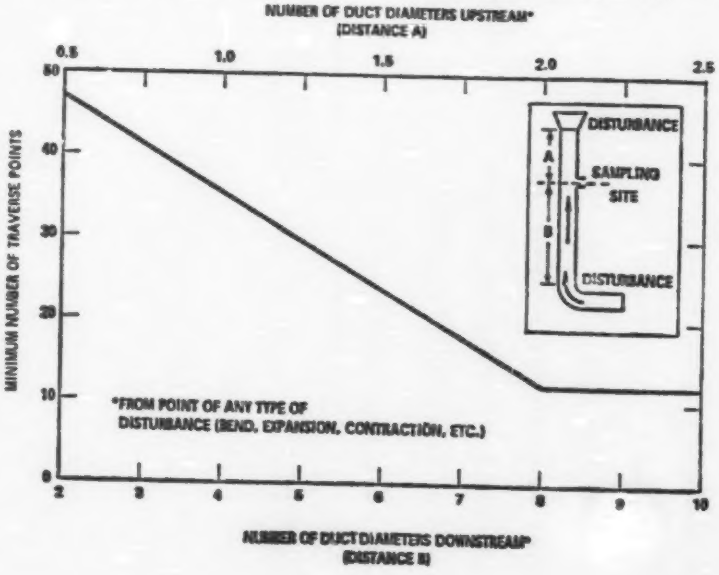

Figure 1-1. Minimum number of traverse points.

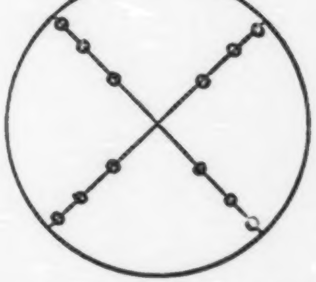

Figure 1-2. Cross section of circular stack showing location of traverse points on perpendicular diameters.

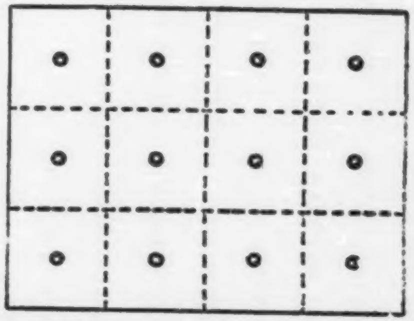

Figure 1-3. Cross section of rectangular stack divided into 12 equal areas, with traverse points at centroid of each area.

Table 1-1. Location of traverse points in circular stacks
(Percent of stack diameter from inside wall to traverse point)

| Traverse point number on a diameter | Number of traverse points on a diameter | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 |
| 1 | 4.4 | 3.3 | 2.5 | 2.1 | 1.8 | 1.6 | 1.4 | 1.3 | 1.1 | 1.1 |
| 2 | 14.7 | 10.5 | 8.2 | 6.7 | 5.7 | 4.9 | 4.4 | 3.9 | 3.5 | 3.2 |
| 3 | 29.5 | 19.4 | 14.6 | 11.8 | 9.9 | 8.5 | 7.5 | 6.7 | 6.0 | 5.5 |
| 4 | 70.5 | 32.3 | 22.6 | 17.7 | 14.6 | 12.5 | 10.9 | 9.7 | 8.7 | 7.9 |
| 5 | 85.3 | 67.7 | 34.2 | 25.0 | 20.1 | 16.9 | 14.6 | 12.9 | 11.6 | 10.5 |
| 6 | 95.6 | 80.6 | 65.8 | 35.5 | 26.9 | 22.0 | 18.8 | 16.5 | 14.6 | 13.2 |
| 7 | | 89.5 | 77.4 | 64.5 | 36.6 | 28.3 | 23.6 | 20.4 | 18.0 | 16.1 |
| 8 | | 96.7 | 85.4 | 75.0 | 63.4 | 37.5 | 29.6 | 25.0 | 21.8 | 19.4 |
| 9 | | | 91.8 | 82.3 | 73.1 | 62.5 | 38.2 | 30.6 | 26.1 | 23.0 |
| 10 | | | 97.5 | 88.2 | 79.9 | 71.7 | 61.8 | 38.8 | 31.5 | 27.2 |
| 11 | | | | 93.3 | 85.4 | 78.0 | 70.4 | 61.2 | 39.3 | 32.3 |
| 12 | | | | 97.9 | 90.1 | 83.1 | 76.4 | 69.4 | 60.7 | 39.8 |
| 13 | | | | | 94.3 | 87.5 | 81.2 | 75.0 | 68.5 | 60.2 |
| 14 | | | | | 98.2 | 91.5 | 85.4 | 79.6 | 73.9 | 67.7 |
| 15 | | | | | | 95.1 | 89.1 | 83.5 | 78.2 | 72.8 |
| 16 | | | | | | 98.4 | 92.5 | 87.1 | 82.0 | 77.0 |
| 17 | | | | | | | 95.6 | 90.3 | 85.4 | 80.6 |
| 18 | | | | | | | 98.6 | 93.3 | 88.4 | 83.9 |
| 19 | | | | | | | | 96.1 | 91.3 | 86.8 |
| 20 | | | | | | | | 98.7 | 94.0 | 89.5 |
| 21 | | | | | | | | | 96.5 | 92.1 |
| 22 | | | | | | | | | 98.9 | 94.5 |
| 23 | | | | | | | | | | 96.8 |
| 24 | | | | | | | | | | 98.9 |

2.2.2. For rectangular stacks divide the cross section into as many equal rectangular areas as traverse points, such that the ratio of the length to the width of the elemental areas is between one and two. Locate the traverse points at the centroid of each equal area according to Figure 1-3.

3. *References.* Determining Dust Concentration in a Gas Stream. ASME Performance Test Code #27. New York. 1957.

Devorkin, Howard, et al. Air Pollution Source Testing Manual. Air Pollution Control District. Los Angeles. November 1963.

Methods for Determination of Velocity, Volume, Dust and Mist Content of Gases. Western Precipitation Division of Joy Manufacturing Co. Los Angeles. Bulletin WP-50. 1968.

Standard Method for Sampling Stacks for Particulate Matter. In: 1971 Book of ASTM Standards, Part 23. Philadelphia, 1971. ASTM Designation D-2928-71.

### METHOD 2—DETERMINATION OF STACK GAS VELOCITY (TYPE S PITOT TUBE)

1. *Principle and applicability.*

1.1 Principle. Stack gas velocity is determined from the gas density and from measurement of the velocity head using a Type S (Stauscheibe or reverse type) pitot tube.

1.2 Applicability. This method should be applied only when specified by the test procedures for determining compliance with New Source Performance Standards. Being a directional instrument, a pitot tube should not be used in the case of nondirectional flow.

2. *Apparatus.*

2.1 Pitot tube—Type S (Figure 2-1), or equivalent.

2.2 Differential pressure gauge—Inclined manometer, or equivalent, to measure velocity head to within 10 percent of the minimum value.

2.3. Temperature gauge—Thermocouples, bimetallic thermometers, liquid filled systems, or equivalent, to measure stack temperature to within 1.5 percent of the minimum absolute stack temperature.

2.4 Pressure gauge—Mercury-filled U-tube manometer, or equivalent, to measure stack pressure to within 0.1 in. Hg.

2.5 Barometer—To measure atmospheric pressure to within 0.1 in. Hg.

2.6 Gas analyzer—To analyze gas composition for determining molecular weight.

2.7 Pitot tube—Standard type, to calibrate Type S pitot tube.

3. *Procedure.*

3.1 Set up the apparatus as shown in Figure 2-1. Make sure all connections are tight and leak free. Measure the velocity head at the traverse points specified by Method 1.

3.2 Measure the temperature of the stack gas. If the total temperature variation with time is less than 50° F., a point measurement will suffice. Otherwise, conduct a temperature traverse.

3.3 Measure the static pressure in the stack.

3.4 Determine the stack gas molecular weight by gas analysis and appropriate calculation as indicated in Method 3.

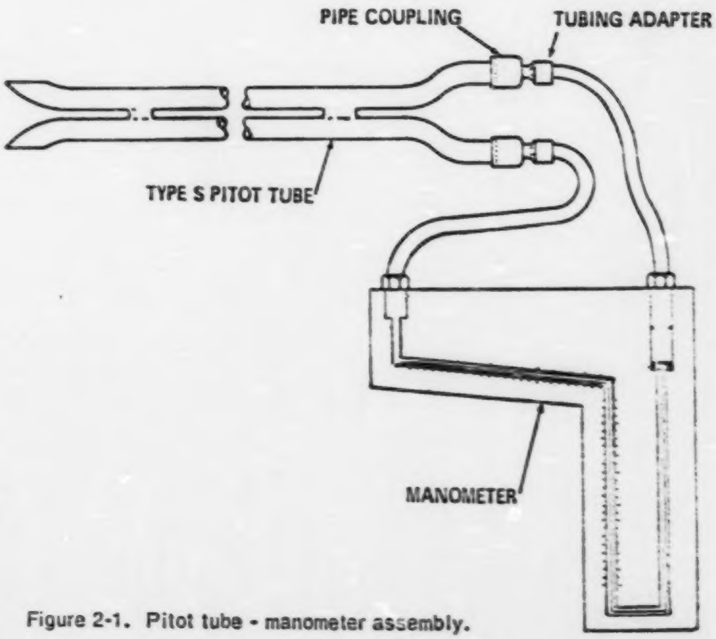

Figure 2-1. Pitot tube - manometer assembly.

4. *Calibration.*

4.1 To calibrate the pitot tube, measure the velocity head at some point in a flowing gas stream with both a Type S pitot tube and a standard type pitot tube with known coefficient. The velocity of the flowing gas stream should be within the normal working range.

4.2 Calculate the pitot tube coefficient using Equation 2-1.

$$C_{p_{test}} = C_{p_{std}} \sqrt{\frac{\Delta P_{std}}{\Delta P_{test}}} \qquad \text{equation 2-1}$$

where:

$C_{p_{test}}$ = Pitot tube coefficient of Type S pitot tube.

$C_{p_{std}}$ = Pitot tube coefficient of standard type pitot tube (if unknown, use 0.99).

$\Delta P_{std}$ = Velocity head measured by standard type pitot tube.

$\Delta P_{test}$ = Velocity head measured by Type S pitot tube.

4.3 Compare the coefficients of the Type S pitot tube determined first with one leg and then the other pointed downstream. Use the pitot tube only if the two coefficients differ by no more than 0.01.

5. *Calculations.*

Use Equation 2-2 to calculate the stack gas velocity.

$$V_s = K_p C_p \sqrt{\frac{T_s \Delta_p}{P_s M_s}} \qquad \text{equation 2-2}$$

where:

$V_s$ = Stack gas velocity, feet per second (f.p.s.).

$K_p = 85.48 \frac{\text{ft.}}{\text{sec.}} \left(\frac{\text{lb.}}{\text{lb. mole-°R}}\right)^{1/2}$ when these units are used.

$C_p$ = Pitot tube coefficient, dimensionless.

$T_s$ = Absolute stack gas temperature, °R.

$\Delta_p$ = Velocity head of stack gas, in $H_2O$ (see fig. 2-2).

$P_s$ = Absolute stack gas pressure, in Hg.

$M_s$ = Molecular weight of stack gas, lb./lb.-mole.

PLANT____________________________

DATE____________________________

RUN NO.____________________________

STACK DIAMETER, in.__________________

BAROMETRIC PRESSURE, in. Hg.____________

STATIC PRESSURE IN STACK ($P_g$), in. Hg.________

OPERATORS__________________________

SCHEMATIC OF STACK CROSS SECTION

| Traverse point number | Velocity head, in. $H_2O$ | $\sqrt{\Delta_p}$ | Stack Temperature ($T_s$) °F |
|---|---|---|---|
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Figure 2-2. Velocity traverse data.

Figure 2-2 shows a sample recording sheet for velocity traverse data. Use the averages in the last two columns of Figure 2-2 to determine the average stack gas velocity from Equation 2-2.

6. *References.*

Mark, L. S. Mechanical Engineers' Handbook. McGraw-Hill Book Co., Inc., New York, 1951.

Perry, J. H. Chemical Engineers' Handbook. McGraw-Hill Book Co., Inc., New York, 1960.

Shigehara, R. T., W. F. Todd, and W. S. Smith. Significance of Errors in Stack Sampling Measurements. Paper presented at the Annual Meeting of the Air Pollution Control Association, St. Louis, Mo., June 14-19, 1970.

Standard Method for Sampling Stacks for Particulate Matter. In: 1971 Book of ASTM standards, Part 23. Philadelphia, 1971. ASTM Designation D-2928-71.

Vennard, J. K. Elementary Fluid Mechanics. John Wiley and Sons, Inc., New York, 1947.

## METHOD 3—GAS ANALYSIS FOR CARBON DIOXIDE, EXCESS AIR, AND DRY MOLECULAR WEIGHT

1. *Principle and applicability.*

1.1 Principle. An integrated or grab gas sample is extracted from a sampling point and analyzed for its components using an Orsat analyzer.

1.2 Applicability. This method should be applied only when specified by the test procedures for determining compliance with New Source Performance Standards.

2. *Apparatus.*

2.1 Grab sample (Figure 3-1).

2.1.1 Probe—Stainless steel or Pyrex[1] glass, equipped with a filter to remove particulate matter.

2.1.2 Pump—One-way squeeze bulb, or equivalent, to transport gas sample to analyzer.

2.2 Integrated sample (Figure 3-2).

2.2.1 Probe—Stainless steel or Pyrex[1] glass equipped with a filter to remove particulate matter.

2.2.2 Air-cooled condenser—To remove any excess moisture.

2.2.3 Needle valve—To adjust flow rate.

2.2.4 Pump—Leak-free, diaphragm type, or equivalent, to pull gas.

2.2.5 Rate meter—To measure a flow range from 0 to 0.035 c.f.m.

2.2.6 Flexible bag—Tedlar,[1] or equivalent, with a capacity of 2 to 3 cu. ft. Leak test the bag in the laboratory before using.

2.2.7 Pitot tube—Type S, or equivalent, attached to the probe so that the sampling flow rate can be regulated proportional to the stack gas velocity when velocity is varying with time or a sample traverse is conducted.

2.3 Analysis.

2.3.1 Orsat analyzer, or equivalent.

3. *Procedure.*

3.1 Grab sampling.

3.1.1 Set up the equipment as shown in Figure 3-1. Place the probe in the stack at a sampling point and purge the sampling line.

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[1] Trade name.

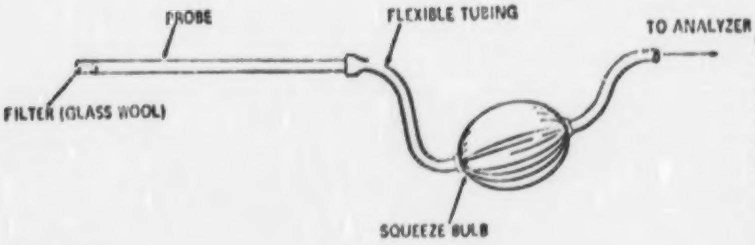

Figure 3-1. Grab-sampling train.

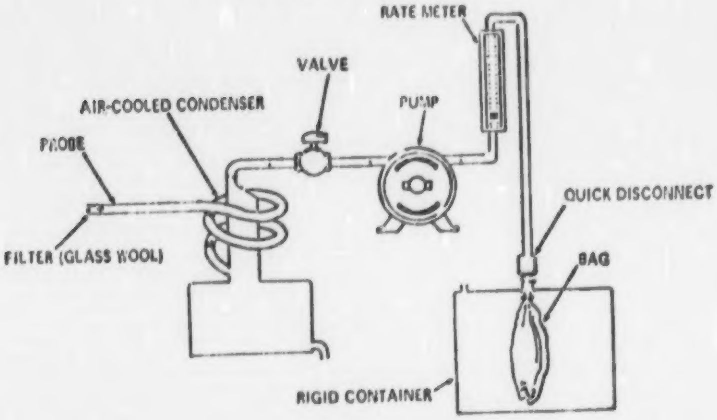

Figure 3-2. Integrated gas - sampling train.

3.1.2 Draw sample into the analyzer.

3.2 Integrated sampling.

3.2.1 Evacuate the flexible bag. Set up the equipment as shown in Figure 3-2 with the bag disconnected. Place the probe in the stack and purge the sampling line. Connect the bag, making sure that all connections are tight and that there are no leaks.

3.2.2 Sample at a rate proportional to the stack gas velocity.

3.3 Analysis.

3.3.1 Determine the $CO_2$, $O_2$, and CO concentrations as soon as possible. Make as many passes as are necessary to give constant readings. If more than 10 passes are necessary, replace the absorbing solution.

3.3.2 For integrated sampling, repeat the analysis until three consecutive runs vary no more than 0.2 percent by volume for each component being analyzed.

4. *Calculations.*

4.1 Carbon dioxide. Average the three consecutive runs and report result to the nearest 0.1 percent $CO_2$.

4.2 Excess air. Use Equation 3-1 to calculate excess air, and average the runs. Report the result to the nearest 0.1 percent excess air.

$$\%\,EA = \frac{(\%\,O_2)-0.5(\%\,CO)}{0.264(\%\,N_2)-(\%\,O_2)+0.5(\%\,CO)} \times 100$$

equation 3-1

where:

$\%EA$ = Percent excess air.

$\%O_2$ = Percent oxygen by volume, dry basis.

$\%N_2$ = Percent nitrogen by volume, dry basis.

$\%CO$ = Percent carbon monoxide by volume, dry basis.

0.264 = Ratio of oxygen to nitrogen in air by volume.

4.3 Dry molecular weight. Use Equation 3-2 to calculate dry molecular weight and average the runs. Report the result to the nearest tenth.

$$M_d = 0.44(\%\,CO_2)+0.32(\%\,O_2)+0.28(\%\,N_2+\%\,CO)$$

Equation 3-2

where:

$M_d$ = Dry molecular weight, lb./lb.-mole.

$\%CO_2$ = Percent carbon dioxide by volume, dry basis.

$\%O_2$ = Percent oxygen by volume, dry basis.

$\%N_2$ = Percent nitrogen by volume, dry basis.

0.44 = Molecular weight of carbon dioxide divided by 100.

0.32 = Molecular weight of oxygen divided by 100.

0.28 = Molecular weight of nitrogen divided by 100.

5. *References*

Altshuller, A. P., et al. Storage of Gases and Vapors in Plastic Bags. Int. J. Air & Water Pollution. 6:75-81. 1963.

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## METHOD 5.—DETERMINATION OF PARTICULATE EMISSIONS FROM STATIONARY SOURCES

1. *Principle and applicability.*

1.1 Principle. Particulate matter is withdrawn isokinetically from the source and its weight is determined gravimetrically after removal of uncombined water.

1.2 Applicability. This method is applicable for the determination of particulate emissions from stationary sources only when specified by the test procedures for determining compliance with New Source Performance Standards.

2. *Apparatus.*

2.1 Sampling train. The design specifications of the particulate sampling train used by EPA (Figure 5-1) are described in APTD-0581. Commercial models of this train are available.

2.1.1 Nozzle—Stainless steel (316) with sharp, tapered leading edge.

2.1.2 Probe—Pyrex[1] glass with a heating system capable of maintaining a gas temperature of 250° F. at the exit end during sampling. When temperature or length limitations are encountered, 316 stainless steel, or equivalent, may be used, as approved by the Administrator.

2.1.3 Pitot tube—Type S, or equivalent, attached to probe to monitor stack gas velocity.

2.1.4 Filter holder—Pyrex[1] glass with heating system capable of maintaining any temperature to a maximum of 225° F.

2.1.5 Impingers—Four impingers connected in series with glass ball joint fittings. The first, third, and fourth impingers are of the Greenburg-Smith design, modified by replacing the tip with a ½-inch ID glass tube extending to ½-inch from the bottom of the flask. The second impinger is of the Greenburg-Smith design with the standard tip.

2.1.6 Metering system—Vacuum gauge, leak-free pump, thermometers capable of measuring temperature to within 5° F., dry gas meter with 2 percent accuracy, and related equipment, or equivalent, as required to maintain an isokinetic sampling rate and to determine sample volume.

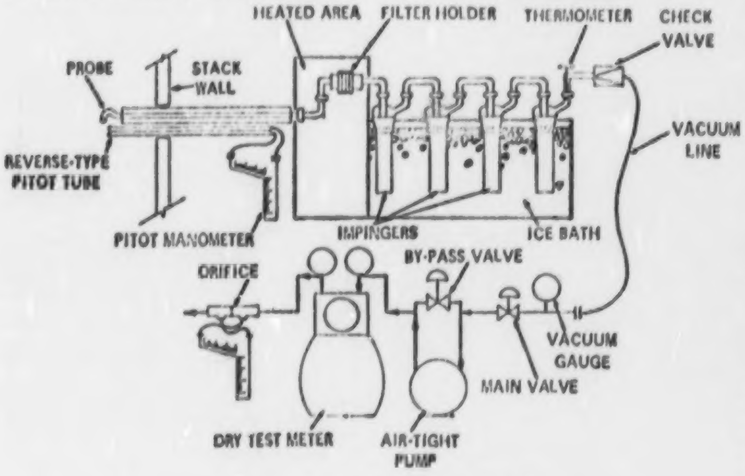

Figure 5-1. Particulate-sampling train.

2.1.7 Barometer—To measure atmospheric pressure to ±0.1 in. Hg.

2.2 Sample recovery.

2.2.1 Probe brush—At least as long as probe.

2.2.2 Glass wash bottles—Two.

2.2.3 Glass sample storage containers.

2.2.4 Graduated cylinder—250 ml.

2.3 Analysis.

2.3.1 Glass weighing dishes.

2.3.2 Desiccator.

2.3.3 Analytical balance—To measure to ±0.1 mg.

2.3.4 Beakers—250 ml.

2.3.5 Separatory funnels—500 ml. and 1,000 ml.

2.3.6 Trip balance—300 g. capacity, to measure to ±0.05 g.

2.3.7 Graduated cylinder—25 ml.

3. *Reagents.*

3.1 Sampling

3.1.1 Filters—Glass fiber, MSA 1106 BH, or equivalent, numbered for identification and preweighed.

3.1.2 Silica gel—Indicating type, 6 to 16 mesh, dried at 175° C. (350° F.) for 2 hours.

3.1.3 Water—Deionized, distilled.

3.1.4 Crushed ice.

3.2 Sample recovery

3.2.1 Water—Deionized, distilled.

3.2.2 Acetone—Reagent grade.

3.3 Analysis

3.3.1 Water—Deionized, distilled.

3.3.2 Chloroform—Reagent grade.

3.3.3 Ethyl ether—Reagent grade.

3.3.4 Desiccant—Drierite,[1] indicating.

4. *Procedure.*

4.1 Sampling.

4.1.1 After selecting the sampling site and the minimum number of sampling points, determine the stack pressure, temperature, moisture, and range of velocity head.

4.1.2 Preparation of collection train. Weigh to the nearest gram approximately 200 g. of silica gel. Label a filter of proper diameter, desiccate[2] for at least 24 hours and weigh to the nearest 0.5 mg. in a room where the relative humidity is less than 50 percent. Place 100 ml. of water in each of the first two impingers, leave the third impinger empty, and place approximately 200 g. of preweighed silica gel in the fourth impinger. Save a portion of the water for use as a blank in the sample analysis. Set up the train without the probe as in Figure 5-1. Leak check the sampling train at the sampling site by plugging the inlet to the filter holder and pulling a 15-in. Hg vacuum. A leakage rate not in excess of 0.02 c.f.m. at a vacuum of 15-in. Hg is acceptable. Attach the probe and adjust the heater to provide a gas temperature of about 250° F. at the probe outlet. Turn on the filter heating system. Place crushed ice around the impingers. Add more ice during the run to keep the temperature of the gases leaving the last impinger at 70° F. or less.

4.1.3 Particulate train operation. For each run record the data required on the example sheet shown in Figure 5-2. Take readings at each sampling point at least every 5 minutes and when significant changes in stack conditions necessitate additional adjustments in flow rate. To begin sampling, position the nozzle at the first traverse point with the tip pointing directly into the gas stream. Immediately start the pump and adjust the flow to isokinetic conditions. Maintain isokinetic sampling throughout the sampling period. Nomographs are available which aid in the rapid adjustment of the sampling rate without other computations. APTD-0576 details the procedure for using these nomographs. Turn off the pump at the conclusion of each run and record the final readings. Remove the probe and nozzle from the stack and handle in accordance with the sample recovery process described in section 4.2.

---

[1] Trade name.

[2] Dry using Drierite[1] at 70° ± 10° F.

PLANT______________
LOCATION______________
OPERATOR______________
DATE______________
RUN NO.______________
SAMPLE BOX NO.______________
METER BOX NO.______________
METER $\Delta H_@$______________
C FACTOR______________

SCHEMATIC OF STACK CROSS SECTION

AMBIENT TEMPERATURE________
BAROMETRIC PRESSURE________
ASSUMED MOISTURE, %________
HEATER BOX SETTING________
PROBE LENGTH, in.________
NOZZLE DIAMETER, in.________
PROBE HEATER SETTING________

| TRAVERSE POINT NUMBER | SAMPLING TIME (θ), min. | STATIC PRESSURE ($P_s$), in. Hg. | STACK TEMPERATURE ($T_s$), °F | VELOCITY HEAD ($\Delta P_s$), | PRESSURE DIFFERENTIAL ACROSS ORIFICE METER ($\Delta H$), in. $H_2O$ | GAS SAMPLE VOLUME ($V_m$), ft³ | GAS SAMPLE TEMPERATURE AT DRY GAS METER | | SAMPLE BOX TEMPERATURE, °F | IMPINGER TEMPERATURE, °F |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | INLET ($T_{m\,in}$), °F | OUTLET ($T_{m\,out}$), °F | | |
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| | | | | | | | | | | |
| TOTAL | | | | | | | Avg. | Avg. | | |
| AVERAGE | | | | | | | Avg. | | | |

Figure 5-2. Particulate field data.

4.2 *Sample recovery.* Exercise care in moving the collection train from the test site to the sample recovery area to minimize the loss of collected sample or the gain of extraneous particulate matter. Set aside portions of the water and acetone used in the sample recovery as blanks for analysis. Place the samples in containers as follows:

Container No. 1. Remove the filter from its holder, place in this container, and seal.

Container No. 2. Place loose particulate matter and acetone washings from all sample-exposed surfaces prior to the filter in this container and seal. Use a razor blade, brush, or rubber policeman to loosen adhering particles.

Container No. 3. Measure the volume of water from the first three impingers and place the water in this container. Place water rinsings of all sample-exposed surfaces between the filter and fourth impinger in this container prior to sealing.

Container No. 4. Transfer the silica gel from the fourth impinger to the original container and seal. Use a rubber policeman as an aid in removing silica gel from the impinger.

Container No. 5. Thoroughly rinse all sample-exposed surfaces between the filter and fourth impinger with acetone, place the washings in this container, and seal.

4.3 *Analysis.* Record the data required on the example sheet shown in Figure 5-3. Handle each sample container as follows:

Container No. 1. Transfer the filter and any loose particulate matter from the sample container to a tared glass weighing dish, dessicate, and dry to a constant weight. Report results to the nearest 0.5 mg.

Container No. 2. Transfer the acetone washings to a tared beaker and evaporate to dryness at ambient temperature and pressure. Dessicate and dry to a constant weight. Report results to the nearest 0.5 mg.

Container No. 3. Extract organic particulate from the impinger solution with three 25 ml. portions of chloroform. Complete the extraction with three 25 ml. portions of ethyl ether. Combine the ether and chloroform extracts, transfer to a tared beaker and evaporate at 70° F. until no solvent remains. Dessicate, dry to a constant weight, and report the results to the nearest 0.5 mg.

Container No. 4. Weigh the spent silic gel and report to the nearest gram.

PLANT____________________

DATE____________________

RUN NO.____________________

| CONTAINER NUMBER | WEIGHT OF PARTICULATE COLLECTED, mg | | |
|---|---|---|---|
| | FINAL WEIGHT | TARE WEIGHT | WEIGHT GAIN |
| 1 | | | |
| 2 | | | |
| 3a* | | | |
| 3b** | | | |
| 5 | | | |
| TOTAL | ☒ | ☒ | |

*3a - ORGANIC EXTRACT FRACTION.
**3b - RESIDUAL WATER FRACTION.

| | VOLUME OF LIQUID WATER COLLECTED | |
|---|---|---|
| | IMPINGER VOLUME, ml | SILICA GEL WEIGHT, g |
| FINAL | | |
| INITIAL | | |
| LIQUID COLLECTED | | |
| TOTAL VOLUME COLLECTED | | g* ml |

*CONVERT WEIGHT OF WATER TO VOLUME BY DIVIDING TOTAL WEIGHT INCREASE BY DENSITY OF WATER. (1 g/ml):

$$\frac{\text{INCREASE, g}}{(1\text{ g/ml})} = \text{VOLUME WATER, ml}$$

Figure 5-3. Analytical data.

Container No. 5. Transfer the acetone washings to a tared beaker and evaporate to dryness at ambient temperature and pressure. Desiccate, dry to a constant weight, and report the results to the nearest 0.5 mg.

5. *Calibration.*

Use standard methods and equipment approved by the Administrator to calibrate the orifice meter, pitot tube, dry gas meter, and probe heater.

6. *Calculations.*

6.1 Sample concentration method.

6.1.1 Average dry gas meter temperature. See data sheet (Figure 5-2).

6.1.2 Dry gas volume. Correct the sample volume measured by the dry gas meter to standard conditions (70° F., 29.92 in. Hg) by using Equation 5-1.

$$V_{m_{std}} = V_m\left(\frac{T_{std}}{T_m}\right)\left(\frac{P_{bar}+\frac{\Delta H}{13.6}}{P_{std}}\right) = \left(17.71\ \frac{°\text{R}}{\text{in. Hg}}\right)(V_m)\left(\frac{P_{bar}+\frac{\Delta H}{13.6}}{P_{std}}\right)$$

equation 5-1

where:

$V_{m_{std}}$ = Volume of gas sample through the dry gas meter (standard conditions), cu. ft.

$V_m$ = Volume of gas sample through the dry gas meter (meter conditions), cu. ft.

$T_{std}$ = Absolute temperature at standard conditions, 530 °R.

$T_m$ = Average dry gas meter temperature, °R.

$P_{bar}$ = Barometric pressure at the orifice meter, in. Hg.

$\Delta H$ = Pressure drop across the orifice meter, in $H_2O$.

13.6 = Specific gravity of mercury.

$P_{std}$ = Absolute pressure at standard conditions, 29.92 in. Hg.

6.1.3 Volume of Water vapor.

$$V_{w_{std}} = V_{l_c}\left(\frac{\rho_{H_2O}}{M_{H_2O}}\right)\left(\frac{RT_{std}}{P_{std}}\right) = \left(0.0474\ \frac{\text{cu. ft.}}{\text{ml.}}\right)V_{l_c}$$

equation 5-2

where:

$V_{w_{std}}$ = Volume of water vapor in the gas sample (standard conditions), cu. ft.

$V_{l_c}$ = Total volume of liquid collected in impingers and silica gel (see Figure 5-3), ml.

$\rho_{H_2O}$ = Density of water, 1 g./ml.

$M_{H_2O}$ = Molecular weight of water, 18 lb./lb. mole.

R = Ideal gas constant, 21.83 in Hg-cu. ft./lb. mole-°R.

$T_{std}$ = Absolute temperature at standard conditions, 530° R.

$P_{std}$ = Absolute pressure at standard conditions, 29.92 in. Hg.

6.1.4 Total gas volume.

$$V_{total} = V_{m_{std}} + V_{w_{std}}$$

equation 5-3

where:

$V_{total}$ = Total volume of gas sample (standard conditions), cu. ft.

$V_{m_{std}}$ = Volume of gas through dry gas meter (standard conditions), cu. ft.

$V_{w_{std}}$ = Volume of water vapor in the gas sample (standard conditions), cu. ft.

6.1.5 Total particulate weight. Determine the total particulate catch from the sum of the weights on the analysis data sheet (Figure 5-3).

6.1.6 Concentration.

$$c_s' = \left(0.0154\ \frac{\text{gr.}}{\text{mg.}}\right)\left(\frac{M_n}{V_{total}}\right)$$

equation 5-4

where:

$c'_s$ = Concentration of particulate matter in stack gas (Sample Concentration Method), gr./s.c.f.

$M_n$ = Total amount of particulate matter collected, mg.

$V_{total}$ = Total volume of gas sample (standard conditions), cu. ft.

6.2 Ratio of area method.

6.2.1 Stack gas velocity. Collect the necessary data as detailed in Method 2. Correct the stack gas velocity to standard conditions (29.92 in. Hg, 530° R.) as follows:

$$V_{s_{std}}=V_s\left(\frac{P_s}{P_{std}}\right)\left(\frac{T_{std}}{T_s}\right)=\left(17.71\,\frac{°R}{\text{in. Hg}}\right)\left(\frac{V_sP_s}{T_s}\right)\quad\text{equation 5-5}$$

where:

$V_{s_{std}}$=Stack gas velocity at standard conditions, ft./sec.

$V_s$=Stack gas velocity calculated by Method 2, Equation 2-2, ft./sec.

$P_s$=Absolute stack gas pressure, in. Hg.

$P_{std}$=Absolute pressure at standard conditions, 29.92 in. Hg.

$T_{std}$=Absolute temperature at standard conditions, 530° R.

$T_s$=Absolute stack gas temperature (average), °R.

6.2.2 Concentration.

$$c_s=\frac{M_n}{Q_s}=\frac{\frac{M_n}{\theta}\,\frac{A_s}{A_n}}{A_sV_{s_{std}}}=\left(2.57\times10^{-4}\,\frac{\text{gr.}-\text{min.}}{\text{mg.}-\text{sec.}}\right)\left(\frac{M_n}{\theta V_{s_{std}}A_n}\right)\quad\text{equation 5-6}$$

where:

$c_s$=Concentration of particulate matter in the stack gas (Ratio of Area Method), gr./s.c.f.

$M_s$=Particulate mass flow rate through the stack (standard conditions), mass/time.

$Q_s$=Volumetric flow rate of gas stream through the stack (standard conditions), volume/time.

$M_n$=Total amount of particulate matter collected by train, mg.

$\theta$=Total sampling time, min.

$A_s$=Cross-sectional area of stack, sq. ft.

$A_n$=Cross-sectional area of nozzle, sq. ft.

$V_{s_{std}}$=Stack gas velocity at standard conditions, ft./sec.

6.3 Isokinetic variation.

$$I=\frac{c_s}{c_s'}\times100=\frac{T_s\left[\frac{V_{l_c}\rho_{H_2O}R}{M_{H_2O}}+\frac{V_m}{T_m}\left(P_{bar}+\frac{\Delta H}{13.6}\right)\right]}{\theta V_sP_sA_n}\times100=$$

$$\frac{\left(1.667\,\frac{\text{min.}}{\text{sec.}}\right)\left[\left(0.00267\,\frac{\text{in. Hg-cu. ft.}}{\text{ml.-}°R}\right)V_{l_c}+\frac{V_m}{T_m}\left(P_{bar}+\frac{\Delta H}{13.6}\right)\right]T_s}{\theta V_sP_sA_n}\quad\text{equation 5-7}$$

where:

I=Percent of isokinetic sampling.

$C_s$=Concentration of particulate matter in the stack gas (Ratio of Area Method), gr./s.c.f.

$C_s'$=Concentration of particulate matter in the stack gas (Sample Concentration Method), gr./s.c.f.

$V_{l_c}$=Total volume of liquid collected in impingers and silica gel (see Figure 5-3), ml.

$\rho_{H_2O}$=Density of water, 1 g./ml.

R=Ideal gas constant, 21.83 in. Hg-cu. ft./lb. mole-°R.

$M_{H_2O}$=Molecular weight of water, 18 lb./lb. mole.

$V_m$=Volume of gas sample through the dry gas meter (meter conditions), cu. ft.

$T_m$=Absolute average dry gas meter temperature (see Figure 5-2), °R.

$P_{bar}$=Barometric pressure at sampling site, in Hg.

$\Delta H$=Average pressure drop across the orifice (see Figure 5-2), in $H_2O$.

$T_s$=Absolute average stack gas temperature (see Figure 5-2), °R.

$\theta$=Total sampling time, min.

$V_s$=Stack gas velocity calculated by Method 2, Equation 2-2, ft./sec.

$P_s$=Absolute stack gas pressure, in. Hg.

$A_n$=Cross-sectional area of nozzle, sq. ft.

6.4 Acceptable results. The following range sets the limit on acceptable isokinetic sampling results:

If 82 percent <I<120 percent, the results are acceptable; otherwise, reject the results and repeat the test.

6.5 Average particulate concentration. If the criteria for acceptability are met, calculate the average concentration of particulate in the stack from the following equation:

$$\bar{c}_s=\frac{c_s+c_s'}{2}\quad\text{Equation 5-8}$$

where:

$\bar{c}_s$=Average particulate concentration in the stack gas, gr./s.c.f.

$c_s$=Concentration of particulate matter in the stack gas (Ratio of Area Method), gr./s.c.f.

$c'_s$=Concentration of particulate matter in the stack gas (Sample Concentration Method), gr./s.c.f.

7. *References.*

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Smith, W. S., et al. Stack Gas Sampling Improved and Simplified with New Equipment. APCA Paper No. 67-119. 1967.

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## METHOD 6—DETERMINATION OF SULFUR DIOXIDE EMISSIONS FROM STATIONARY SOURCES

1. *Principle and applicability.*

1.1 Principle. A gas sample is extracted from the sampling point in the stack, and the acid mist including sulfur trioxide is separated from the sulfur dioxide. The sulfur dioxide fraction is measured by the barium-thorin titration method.

1.2 Applicability. This method is applicable for the determination of sulfur dioxide emissions from stationary sources only when specified by the test procedures for determining compliance with New Source Performance Standards.

2. *Apparatus.*

2.1 Sampling. See Figure 6-1

2.1.1 Probe—Pyrex[1] glass, approximately 5-6 mm. ID, with a heating system to prevent condensation and a filter to remove particulate matter including sulfuric acid mist.

2.1.2 Midget bubbler—One, with glass wool packed in top to prevent sulfuric acid mist carryover.

2.1.3 Glass wool.

2.1.4 Midget impingers—Three.

2.1.5 Drying tube—Packed with 6 to 16 mesh indicating-type silica gel, or equivalent, to dry the sample.

2.1.6 Pump—Leak-free, vacuum type.

2.1.7 Rate meter—Rotameter, or equivalent, to measure a 0-10 s.c.f.h. flow range.

2.1.8 Dry gas meter—Sufficiently accurate to measure the sample volume within 1 percent.

2.1.9 Pitot tube—Type S, or equivalent, necessary only if a sample traverse is required or if stack gas velocity varies with time.

2.2 Sample recovery.

2.2.1 Glass wash bottles—Two.

2.2.2 Polyethylene storage bottles—To store impinger samples.

2.3 Analysis.

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[1] Trade name.

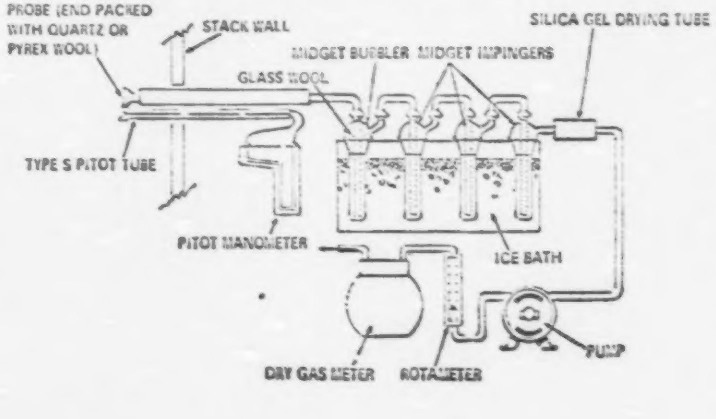

Figure 6-1. $SO_2$ sampling train.

2.3.1 Pipettes—Transfer type, 5 ml. and 10 ml. sizes (0.1 ml. divisions) and 25 ml. size (0.2 ml. divisions).

2.3.2 Volumetric flasks—50 ml., 100 ml., and 1,000 ml.

2.3.3 Burettes—5 ml. and 50 ml.

2.3.4 Erlenmeyer flask—125 ml.

3. *Reagents.*

3.1 Sampling.

3.1.1 Water—Deionized, distilled.

3.1.2 Isopropanol, 80 percent—Mix 80 ml. of isopropanol with 20 ml. of distilled water.

3.1.3 Hydrogen peroxide, 3 percent—dilute 100 ml. of 30 percent hydrogen peroxide with 900 ml. of distilled water. Prepare fresh daily.

3.2 Sample recovery.

3.2.1 Water—Deionized, distilled.

3.2.2 Isopropanol, 80 percent.

3.3 Analysis.

3.3.1 Water—Deionized, distilled.

3.3.2 Isopropanol.

3.3.3 Thorin indicator—1-(o-arsonophenylazo)-2-naphthol-3, 6-disulfonic acid, disodium salt (or equivalent). Dissolve 0.20 g. in 100 ml. distilled water.

3.3.4 Barium perchlorate (0.01*N*)—Dissolve 1.95 g. of barium perchlorate [$Ba(ClO_4)_2 \cdot 3H_2O$] in 200 ml. distilled water and dilute to 1 liter with isopropanol. Standardize with sulfuric acid.

3.3.5 Sulfuric acid standard (0.01*N*)—Purchase or standardize against a primary standard to ±0.0002*N*.

4. *Procedure.*

4.1 Sampling.

4.1.1 Preparation of collection train. Pour 15 ml. of 80 percent isopropanol into the midget bubbler and 15 ml. of 3 percent hydrogen peroxide to each of the first two midget impingers. Leave the final midget impinger dry. Assemble the train as shown in Figure 6-1. Leak check the sampling train at the sampling site by plugging the probe inlet and pulling a 10-in. Hg vacuum. A leakage rate not in excess of 1 percent of the sampling rate is acceptable. Carefully release the probe inlet plug and turn off the pump. Place crushed ice around the impingers. Add more ice during the run to keep the temperature of the gases leaving the last impinger at 70° F. or less.

4.1.2 Sample collection. Adjust the sample flow rate proportional to the stack as velocity. Take readings at least every 5 minutes and when significant changes in stack conditions necessitate additional adjustments in flow rate. To begin sampling, position the nozzle with the tip pointing directly into the gas stream and start the pump. Sample proportionally throughout the run. At the conclusion of each run, turn off the pump and record the final readings. Remove the probe from the stack and disconnect it from the train. Drain the ice bath and purge the remaining part of the train by drawing clean ambient air through the system for 15 minutes.

4.2 Sample recovery. Disconnect the impingers after the purging period. Discard the contents of the midget bubbler. Pour the contents of the midget impingers into a polyethylene shipment bottle. Rinse the three midget impingers and the connecting tubes with distilled water and add these washings to the same storage container.

4.3 Sample analysis. Transfer the contents of the storage container to a 50-ml. volumetric flask. Dilute to the mark with deionized, distilled water. Pipette a 10 ml. aliquot of this solution to a 125-ml. erlenmeyer flask. Add 40 ml. of isopropanol and 2 to 4 drops of thorin indicator. Titrate to a pink endpoint using 0.01*N* barium perchlorate. Run a blank with each series of samples.

5. *Calibration.*

5.1 Use standard methods and equipment approved by the Administrator to calibrate the orifice meter, pitot tube, dry gas meter, and probe heater.

5.2 Standardize the sulfuric acid with potassium acid phthalate as a primary standard. Standardize the barium perchlorate with 25 ml. of standard sulfuric acid containing 100 ml. of isopropanol.

6. *Calculations.*

6.1 Dry gas volume. Correct the sample volume measured by the dry gas meter to standard conditions (70° F. and 29.92 in. Hg) by using Equation 6-1.

$$V_{m_{std}} = V_m\left(\frac{T_{std}}{T_m}\right)\left(\frac{P_{bar}}{P_{std}}\right) = \left(17.71\,\frac{°R}{\text{in. Hg}}\right)\frac{V_m P_{bar}}{T_m} \qquad \text{equation 6-1}$$

where:

$V_{m_{std}}$ = Volume of gas sample through the dry gas meter (standard conditions), cu. ft.

$V_m$ = Volume of gas sample through the dry gas meter (meter conditions), cu. ft.

$T_{std}$ = Absolute temperature at standard conditions, 530° R.

$T_m$ = Average dry gas meter temperature, °R.

$P_{bar}$ = Barometric pressure at the orifice meter, in. Hg.

$P_{std}$ = Absolute pressure at standard conditions, 29.92 in. Hg.

6.2 Sulfur dioxide concentration.

$$c_{SO_2} = \left(7.05\times10^{-5}\,\frac{\text{lb.-l.}}{\text{g.-ml.}}\right)\frac{(V_t - V_{tb})\,(N)\left(\frac{V_{soln}}{V_a}\right)}{V_{m_{std}}} \qquad \text{equation 6-2}$$

where:

$c_{SO_2}$ = Concentration of sulfur dioxide at standard conditions, dry basis, lb./cu. ft.

$7.05\times10^{-5}$ = Conversion factor including the number of grams per gram equivalent of sulfur dioxide (32 g./g.-eq.), 453.6 g./lb., and 1,000 ml./l, lb.-l./g.-ml.

$V_t$ = Volume of barium perchlorate titrant used for the sample, ml.

$V_{tb}$ = Volume of barium perchlorate titrant used for the blank, ml.

$N$ = Normality of barium perchlorate titrant, g.-eq./l.

$V_{soln}$ = Total solution volume of sulfur dioxide, ml.

$V_a$ = Volume of sample aliquot titrated, ml.

$V_{m_{std}}$ = Volume of gas sample through the dry gas meter (standard conditions), see Equation 6-1, cu. ft.

7. *References.*

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Matty, R. E. and E. K. Diehl. Measuring Flue-Gas $SO_2$ and $SO_3$. Power *101*:94-97. November 1957.

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## APPENDIX C

## VISIBLE EMISSIONS REPORTED FROM EPA TESTS AND QUESTIONNAIRE DATA

Visible emissions were read by the EPA project engineer on a random basis during EPA tests. Figure C-1 shows the points of discharge where the emissions were read. Table C-1 reports the emissions in percent opacity corresponding to the emission points numbered in Figure C-1. Point 2 in the figure is used to indicate the furnace is without a control device whereas Point 4 shows that the furnace is equipped with a control device. Covered furnaces H and J have mix seals. Above the mix seals are located a hood and uncontrolled exhaust systems to remove the escaping dust-laden gases from the mix seals. This is shown as Point 6 in Figure C-1. The opacity of these emissions ranges from 10 to 100 percent. Covered furnaces K and L are equipped with fixed seals and do not have hooding and uncontrolled exhaust systems. In these two cases no emissions from the building were noticeable

In most instances, there were no, or very insignificant, noticeable visible emissions from the control equipment. Most noticeable emissions were from uncontrolled furances A and B, the uncontrolled exhaust systems serving the tapping stations, and the uncontrolled exhaust system serving to remove the fugitive fumes from the covered furances with mix seals (H and J).

Table C-2 is a summary of visible emissions reported by the questionnaires submitted by the industry. The reported opacity of the fugitive fumes escaping from the mix seals ranged from 0 to 60 percent. The reported opacity of uncontrolled emissions from open furnaces ranged from 10 to 100 percent.

Whenever possible, emissions were read using the visible emission recording sheet shown in Figure C-2. The second page of Figure C-2 is in reality printed on the reverse side of the visible emission record, and the necessary data relative to the opacity are filled in at the time of the readings.

Table C-1. OPACITY OF EMISSIONS REPORTED FROM EPA TESTS
(%)

| Furnace | Test run | Product | Type of furnace | Uncontrolled fumes | | | Controlled fumes | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Outlet of furnace exhaust system point 2 | Outlet of tapping exhaust system points 3+8 | Outlet of fugitive fume exhaust system point 6 | Type of control equipment | Degree fumes captured est. % | Percent opacity of uncaptured fumes at roof monitor-points 1+5 | Percent opacity of control equipment outlet-points 4+7 |
| A | 1 | FeCrSi | O | 100 | b | | None | | | |
| | 2 | | | 50 to 100 | b | | | | | |
| B | 1 | Cr ore/lime melt | O | 50 to 100 | b | 100[c] | None | | | |
| | 2 | | | 50 to 100 | b | 100[c] | | | | |
| C | 1 | SiMn | O | | | | Venturi(57"PD)* | 99 | 0 | 0 |
| | 2 | | | | | | Venturi(57"PD) | | 0 | 0 |
| | 3 | | | | | | Venturi(57"PD) | | 0 | 0 |
| | 4 | | | | | | Venturi(57"PD) | | 0 | 0 |
| | 5 | | | | | | Venturi(57"PD) | | 0 | 0 |
| | 7 | | | | | | Venturi(47"PD) | 99 | 0 | 0 |
| | 8 | | | | | | Venturi(47"PD) | | 0 | 0 |
| | 9 | | | | | | Venturi(47"PD) | | 0 | 0 |
| | 10 | | | | | | Venturi(37"PD) | 99 | 0 | < 10 |
| | 11 | | | | | | Venturi(37"PD) | | 0 | < 10 |
| | 12 | | | | | | Venturi(37"PD) | | 0 | < 10 |
| D | 1 | FeCrSi | O | | | | Baghouse | 99 | 0 | 0 |
| | 2 | | | | | | Baghouse | | 0 | 0 |
| | 3 | | | | | | Baghouse | | 0 | 0 |
| E | 1 | HC FeCr | O | | | | Precipitator | 99 | | < 5 |
| | 2 | | | | | | Precipitator | | | 5 to 20 |
| | 3 | | | | | | Precipitator | | | 5 to 20 |
| F | 1 | Silicon | O | | 100 | | Baghouse | 95 to 99 | 10 to 20 | 0 |
| | 2 | | | | 100 | | Baghouse | | 10 to 20 | 0 |
| | 3 | | | | 100 | | Baghouse | | 10 to 20 | 0 |
| G | 1 | SiMn | O | | 10 to 80 | | Venturi | 99 | 0 | 0 |
| | 2 | | | | 10 to 80 | | | 99 | 0 | 0 |
| | 3 | | | | 10 to 80 | | | 99 | 0 | 0 |
| H | 1 | 50% FeSi | C | | | 10 to 100 | Venturi | 85 | See point 6 | 0 |
| | 2 | | | | | 10 to 100 | Venturi | | See point 6 | 0 |
| | 3 | | | | | 10 to 100 | Venturi | | See point 6 | 0 |
| J | 1 | $CaC_2$ | C | | | 10 to 100 | Scrubber | | | 0 |
| | 2 | | | | | 10 to 100 | Scrubber | | | 0 |
| | 3 | | | | | 10 to 100 | Scrubber | | | 0 |
| K | 1 | FeMn | C | | 100[d] | | Venturi | 100 | 0 | 0 |
| | 2 | | | | 100[d] | | Venturi | | 0 | 0 |
| | 3 | | | | 100[d] | | Venturi | | 0 | 0 |
| | 4 | | | | 100[d] | | Venturi | | 0 | 0 |
| | 5 | | | | 100[d] | | Venturi | | 0 | 0 |
| L | 1 | SiMn | C | | 100[d] | | Venturi | 100 | 0 | 0 |
| | 2 | | | | 100[d] | | Venturi | | 0 | 0 |
| | 3 | | | | 100[d] | | Venturi | | 0 | 0 |

[a] O = open, C = closed.

[b] Tapping fumes vented to main uncontrolled exhaust system.

[c] Uncaptured fumes escaping through roof monitor.

[d] No exhaust system at tapping point.

Table C-2. OPACITY OF EMISSIONS REPORTED FROM QUESTIONNAIRE DATA

| Questionnaire no. | Product | Uncontrolled fumes |  |  | Controlled fumes |  |
|---|---|---|---|---|---|---|
|  |  | Outlet of furnace exhaust system | Outlet of tapping exhaust system | Fugitive fumes exhaust system | Type of control | Control equipment outlet |
| 87 |  | 80 to 100 | No data reported. |  |  |  |
| 86 |  | 80 to 100 |  |  |  |  |
| 46 |  | 20 to 80 |  |  |  |  |
| 44 |  | 20 to 80 |  |  |  |  |
| 45 |  | 20 to 80 |  |  |  |  |
| 64 | HC FeMn |  |  | 0 to 20 | BF[a] scrubber |  |
| 65 |  |  |  | 20 to 40 | BF scrubber |  |
| 66 |  |  |  | 35 | BF scrubber |  |
| 70 |  |  |  | 10 to 50 | BF scrubber |  |
| 71 |  |  |  | 5 to 30 | BF scrubber |  |
| 73 |  |  |  | 5 to 25 | BF scrubber |  |
| 83 |  |  |  | 0 to 10 | BF scrubber |  |
| 6 |  | 20 to 60 |  |  |  |  |
| 15 |  | 20 to 60 |  |  |  |  |
| 103 | 50-75% FeSi |  |  | 40 to 60 | BF scrubber |  |
| 79 |  |  |  | 20 to 40 | BF scrubber |  |
| 84 |  |  |  | 20 to 40 | BF scrubber |  |
| 68 | 90% FeSi |  |  | 5 to 10 | BF scrubber |  |
| 72 |  |  |  | 15 to 30 | BF scrubber |  |
| 91 |  |  |  | 25 | BF scrubber |  |
| 60 |  |  |  | 10 to 20 | BF scrubber |  |
| 55 |  |  |  | 10 to 20 | BF scrubber |  |
| 54 |  |  |  | 10 to 20 | BF scrubber |  |
| 59 |  |  |  | 10 to 20 | Venturi scrubber |  |
| 8 |  | 10 |  |  |  |  |
| 91 |  | 80 to 100 |  |  |  |  |
| 47 |  | 20 to 80 |  |  |  |  |
| 52 | SiMn |  |  | 20 to 40 | BF scrubber |  |
| 5 |  | 20 to 60 |  |  |  |  |
| 7 |  | 20 to 60 |  |  |  |  |
| 10 |  | 20 to 60 |  |  |  |  |
| 11 |  | 20 to 60 |  |  |  |  |
| 13 |  | 20 to 60 |  |  |  |  |
| 14 |  | 20 to 60 |  |  |  |  |
| 44 |  |  |  | 20 to 40 | BF scrubber |  |
| 74 |  |  |  | 20 to 60 | BF scrubber |  |
| 78 |  |  |  |  | Venturi scrubber | 0 |
| 100 | FeCrSi | 80 to 100 |  |  |  |  |
| 90 |  |  |  |  | Venturi | 0 to 20 |
| 67 | FeCr |  |  | 20 to 30 | BF scrubber |  |
| 69 |  |  |  | 20 to 40 | BF scrubber |  |
| 75 |  |  |  | 20 to 30 | BF scrubber |  |
| 77 |  |  |  |  | Venturi scrubber | 0 |
| 53 | $CaC_2$ |  |  | 20 to 40 | BF scrubber |  |
| 56 |  |  |  | 10 to 35 | BF scrubber |  |
| 57 |  |  |  | 20 to 40 | BF scrubber |  |
| 61 |  |  |  | 20 to 40 | BF scrubber |  |
| 62 |  |  |  | 10 to 35 | BF scrubber |  |
| 58 |  |  |  | 10 | BF scrubber |  |
| 3 | LC & MC FeMn | 5 to 90 |  |  |  |  |
| 114 | CrOre/lime melt | 60 to 80 |  |  |  |  |
| 88 | SiMn2 | 60 to 80 |  |  |  |  |

[a] BF scrubber = Buffalo Forge scrubber.

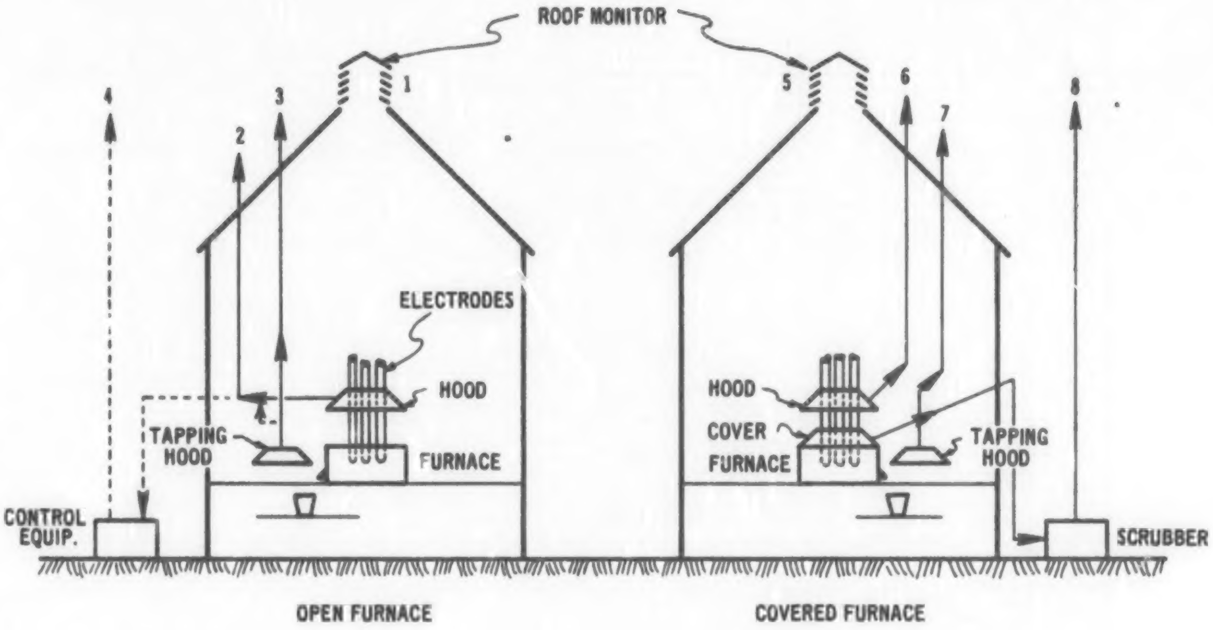
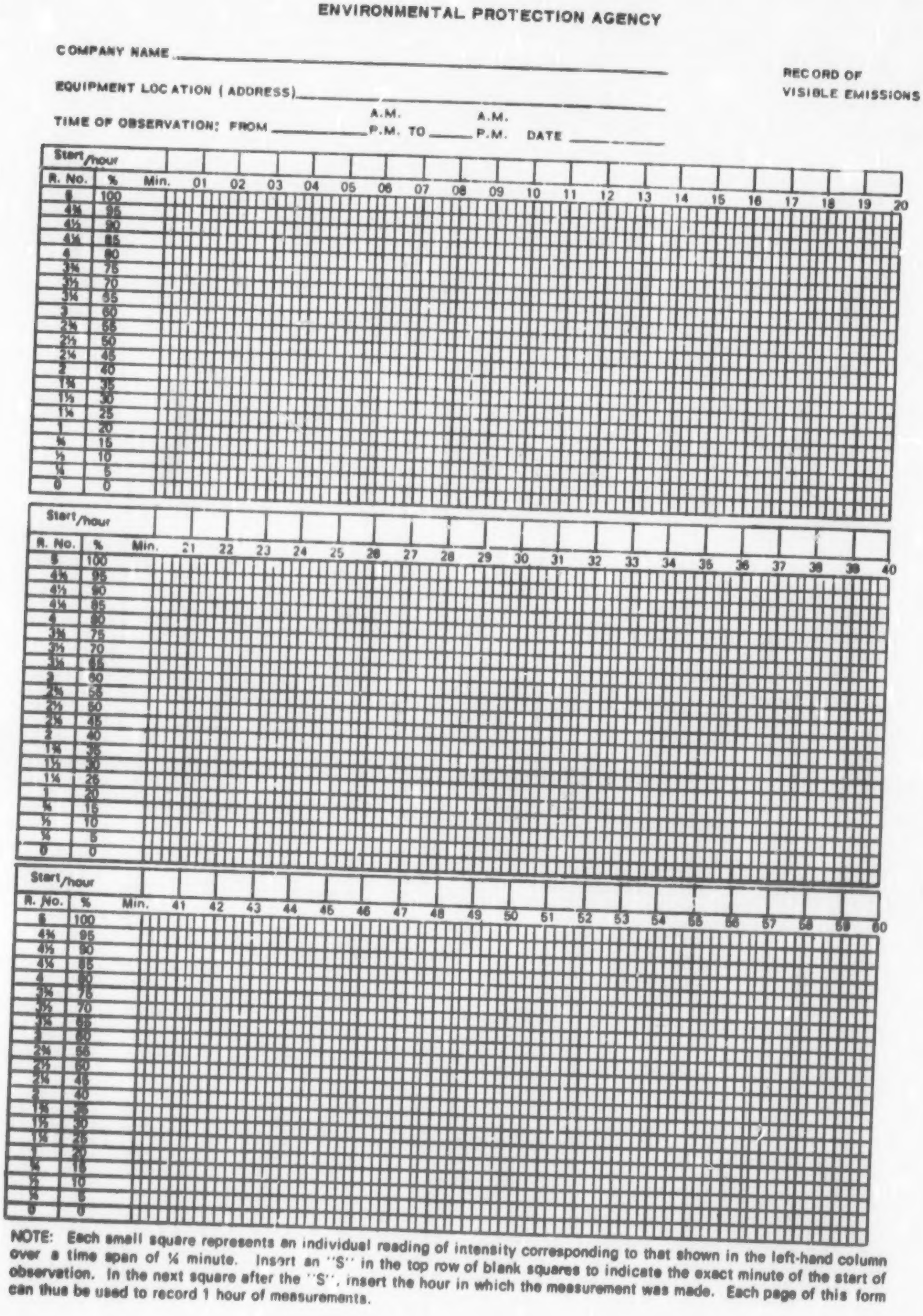

ROOF MONITOR
1
2
3
4
5
6
7
8
ELECTRODES
HOOD
TAPPING HOOD
FURNACE
CONTROL EQUIP.
HOOD
COVER
FURNACE
TAPPING HOOD
SCRUBBER
OPEN FURNACE
COVERED FURNACE

Figure C-1. Emission points where visible emissions were read during EPA tests on open and covered furnaces.



**ENVIRONMENTAL PROTECTION AGENCY**

**RECORD OF VISIBLE EMISSIONS**

COMPANY NAME ____________________

EQUIPMENT LOCATION (ADDRESS) ____________________

TIME OF OBSERVATION: FROM ________ A.M. P.M. TO ______ A.M. P.M. DATE __________

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start/hour | | | | | | | | | | | | | | | | | | | | | | |
| R. No. | % | Min. | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| 5 | 100 | | | | | | | | | | | | | | | | | | | | | |
| 4¾ | 95 | | | | | | | | | | | | | | | | | | | | | |
| 4½ | 90 | | | | | | | | | | | | | | | | | | | | | |
| 4¼ | 85 | | | | | | | | | | | | | | | | | | | | | |
| 4 | 80 | | | | | | | | | | | | | | | | | | | | | |
| 3¾ | 75 | | | | | | | | | | | | | | | | | | | | | |
| 3½ | 70 | | | | | | | | | | | | | | | | | | | | | |
| 3¼ | 65 | | | | | | | | | | | | | | | | | | | | | |
| 3 | 60 | | | | | | | | | | | | | | | | | | | | | |
| 2¾ | 55 | | | | | | | | | | | | | | | | | | | | | |
| 2½ | 50 | | | | | | | | | | | | | | | | | | | | | |
| 2¼ | 45 | | | | | | | | | | | | | | | | | | | | | |
| 2 | 40 | | | | | | | | | | | | | | | | | | | | | |
| 1¾ | 35 | | | | | | | | | | | | | | | | | | | | | |
| 1½ | 30 | | | | | | | | | | | | | | | | | | | | | |
| 1¼ | 25 | | | | | | | | | | | | | | | | | | | | | |
| 1 | 20 | | | | | | | | | | | | | | | | | | | | | |
| ¾ | 15 | | | | | | | | | | | | | | | | | | | | | |
| ½ | 10 | | | | | | | | | | | | | | | | | | | | | |
| ¼ | 5 | | | | | | | | | | | | | | | | | | | | | |
| 0 | 0 | | | | | | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start/hour | | | | | | | | | | | | | | | | | | | | | | |
| R. No. | % | Min. | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 |
| 5 | 100 | | | | | | | | | | | | | | | | | | | | | |
| 4¾ | 95 | | | | | | | | | | | | | | | | | | | | | |
| 4½ | 90 | | | | | | | | | | | | | | | | | | | | | |
| 4¼ | 85 | | | | | | | | | | | | | | | | | | | | | |
| 4 | 80 | | | | | | | | | | | | | | | | | | | | | |
| 3¾ | 75 | | | | | | | | | | | | | | | | | | | | | |
| 3½ | 70 | | | | | | | | | | | | | | | | | | | | | |
| 3¼ | 65 | | | | | | | | | | | | | | | | | | | | | |
| 3 | 60 | | | | | | | | | | | | | | | | | | | | | |
| 2¾ | 55 | | | | | | | | | | | | | | | | | | | | | |
| 2½ | 50 | | | | | | | | | | | | | | | | | | | | | |
| 2¼ | 45 | | | | | | | | | | | | | | | | | | | | | |
| 2 | 40 | | | | | | | | | | | | | | | | | | | | | |
| 1¾ | 35 | | | | | | | | | | | | | | | | | | | | | |
| 1½ | 30 | | | | | | | | | | | | | | | | | | | | | |
| 1¼ | 25 | | | | | | | | | | | | | | | | | | | | | |
| 1 | 20 | | | | | | | | | | | | | | | | | | | | | |
| ¾ | 15 | | | | | | | | | | | | | | | | | | | | | |
| ½ | 10 | | | | | | | | | | | | | | | | | | | | | |
| ¼ | 5 | | | | | | | | | | | | | | | | | | | | | |
| 0 | 0 | | | | | | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start/hour | | | | | | | | | | | | | | | | | | | | | | |
| R. No. | % | Min. | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 |
| 5 | 100 | | | | | | | | | | | | | | | | | | | | | |
| 4¾ | 95 | | | | | | | | | | | | | | | | | | | | | |
| 4½ | 90 | | | | | | | | | | | | | | | | | | | | | |
| 4¼ | 85 | | | | | | | | | | | | | | | | | | | | | |
| 4 | 80 | | | | | | | | | | | | | | | | | | | | | |
| 3¾ | 75 | | | | | | | | | | | | | | | | | | | | | |
| 3½ | 70 | | | | | | | | | | | | | | | | | | | | | |
| 3¼ | 65 | | | | | | | | | | | | | | | | | | | | | |
| 3 | 60 | | | | | | | | | | | | | | | | | | | | | |
| 2¾ | 55 | | | | | | | | | | | | | | | | | | | | | |
| 2½ | 50 | | | | | | | | | | | | | | | | | | | | | |
| 2¼ | 45 | | | | | | | | | | | | | | | | | | | | | |
| 2 | 40 | | | | | | | | | | | | | | | | | | | | | |
| 1¾ | 35 | | | | | | | | | | | | | | | | | | | | | |
| 1½ | 30 | | | | | | | | | | | | | | | | | | | | | |
| 1¼ | 25 | | | | | | | | | | | | | | | | | | | | | |
| 1 | 20 | | | | | | | | | | | | | | | | | | | | | |
| ¾ | 15 | | | | | | | | | | | | | | | | | | | | | |
| ½ | 10 | | | | | | | | | | | | | | | | | | | | | |
| ¼ | 5 | | | | | | | | | | | | | | | | | | | | | |
| 0 | 0 | | | | | | | | | | | | | | | | | | | | | |

**NOTE:** Each small square represents an individual reading of intensity corresponding to that shown in the left-hand column over a time span of ¼ minute. Insert an "S" in the top row of blank squares to indicate the exact minute of the start of observation. In the next square after the "S", insert the hour in which the measurement was made. Each page of this form can thus be used to record 1 hour of measurements.

Figure C-2. Visible emissions recording sheet.

Source of Air Contaminants ______________________________

Type of Air Contaminants ______________________________

Point of Discharge: Stack ☐ Other ______________________________

Point of Observation:

Distance to Base of Point of Discharge, feet ______________________________

Height of Point of Discharge Above Ground Level, feet ______________________________

Background Description ______________________________

Weather: Clear ☐ Overcast ☐ Partly Cloudy ☐ Other ______________________________

Wind Direction ____________ Wind Velocity, mi/hr ____________

Plume Description:

Detached: Yes ☐ No ☐

Color: Black ☐ White ☐ Other ______________________________

Plume Dispersion Behavior: Looping ☐ Coning ☐ Fanning ☐ Lofting ☐ Fumigating ☐ See Comments ☐

Estimated Distance (feet) Plume Visible (Maximum) ________ (Minimum) ________

Comments ______________________________

______________________________

______________________________

______________________________

______________________________

Signed ______________________________ Title ______________________________

Figure C-2. (continued) Visible emissions recording sheet.

## APPENDIX D

## PARTICLE SIZE ANALYSIS

Determination of the size distribution of particles suspended in gases from a submerged-arc furnace is important and is helpful in designing an optimum dust-removal system. Unless capture and recovery is excellent, significant quantities of small particles can be emitted to the atmosphere since nearly all of the particles are less than 1 micron. Very little published information exists on the size distribution of particulate matter from ferroalloy furnaces. Person states that most particles are less than 0.5 micron.[20] This was verified in an EPA-contracted study made by TRW, Inc. This study's data, presented in this appendix, were obtained during the same time tests were made to determine mass emission rates.

Samples of particulates in the gas streams from five electric furnaces and at the outlets of four air pollution control devices were collected by a cascade impactor to determine particle size distribution. The first nine samples were collected using the Andersen sampler. Because the particles were smaller than expected, the majority of the particles passed through the sampler and were deposited on the filter. The Andersen sampler was therefore discarded in favor of the Brink sampler, which was used in gathering the remaining samples.

The basic design of the cascade impactor sampler has been described in detail in literature. The cascade impactor is constructed of a succession of jets, and each jet is smaller than the preceeding one. The sampler is small enough that it can be inserted through a small port in the stack and positioned in the gas stream so that the sample is collected in conditions as close as possible to isokinetic.

The gas streams take a turning path through the impactor. When the velocity of an entrained particle is high enough to overcome aerodynamic drag and escape from the laminar streamline, the particle impacts on a collection area of the plate. If the particle is too small and its inertia too low for removal from the stream, it proceeds with the gas through an orfice in the next plate, and its velocity and inertial effects are increased. Fractionation is not based on physical diameter only, but also on "aerodynamic diameter," which takes into account density and shape. Aerodynamic diameter, in fact, is probably more related to atmosphere behavior and the operation of particulate collection devices than its physical diameter.

The Andersen impactor has a stainless steel sampling head containing nine circular plates, each with several hundred jet-orifices. The size of the orifices becomes progressively smaller in each succeeding downstream plate, so that the velocity of the gas streams that pass through the orifices increases correspondingly. The top part of the photograph of the Andersen sampler in Figure D-1 shows the relative size of the assembled sampler. The lower part of the photograph shows the sampler when disassembled.

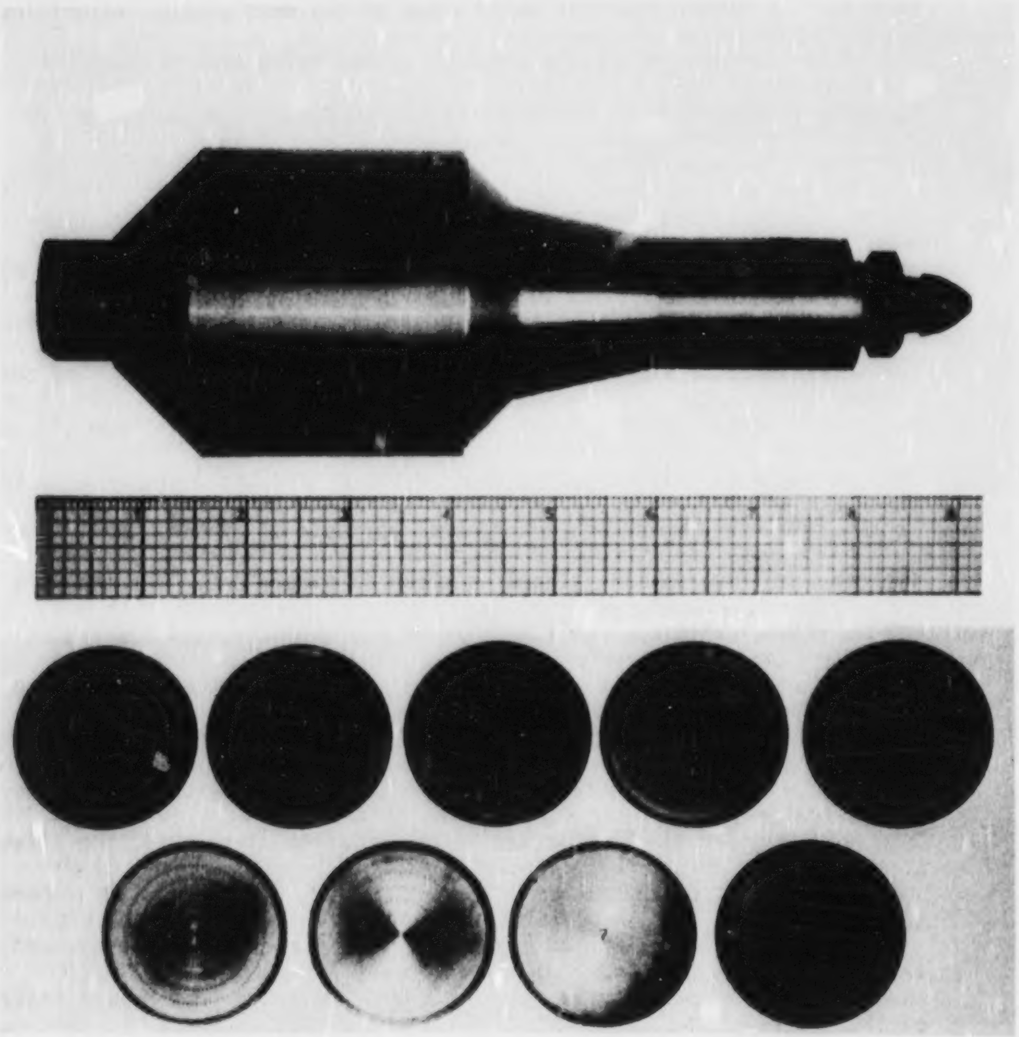


Figure D-1. Andersen sampler showing assembled and disassembled sections.

The second sampler, the Brink cascade impactor, has a single jet orifice for each stage. Each orifice uses a collection cup as an impaction surface rather than the solid areas of the next plate. Velocities are higher through the single orifices of the Brink than through the multiple orifices of the Andersen, so the cups normally have adhesive coatings. The manufacturer indicates that the Brink impactor collects and classifies particles down to 0.25 micron, with more cuts in the fine-particle range than the Andersen sampler. Because it was found that most of the particles from air pollution control devices were below 0.7 micron, the Brink impactor was selected to obtain most of the samples. The characteristic diameter of an aerosol particle for each impactor stage (i.e., Dpc) has been calculated for pressure drops across the impactor of 5 and 10 inches of mercury (based on a spherical particle of density one). The impactor has five in-line stages as shown in Figure D-2. The top part of the figure shows the relative size of the impactor; the lower part shows an enlarged view of the five jet stages. When the pressure drop across the impactor is at 5 inches of mercury, the particles collected are in the size range of 3.4, 2.0, 1.36, 0.69, and 0.42 microns. When the pressure drop across the impactor is at 10 inches of mercury, the sizes of the particles collected are 3.06, 1.80, 1.23, 0.63, and 0.38 microns.

During the tests, the cascade impactor was mounted on a probe and connected to vacuum pumps by rubber tubing. Metering valves were installed on the inlet side of the pump to adjust the air flow through the samplers. Magnehelic gauges were inserted in the system to measure pressure drops across the sampler. Figure D-3 illustrates a typical particle sizing train. Volumetric flow rates through the sampler were measured for long

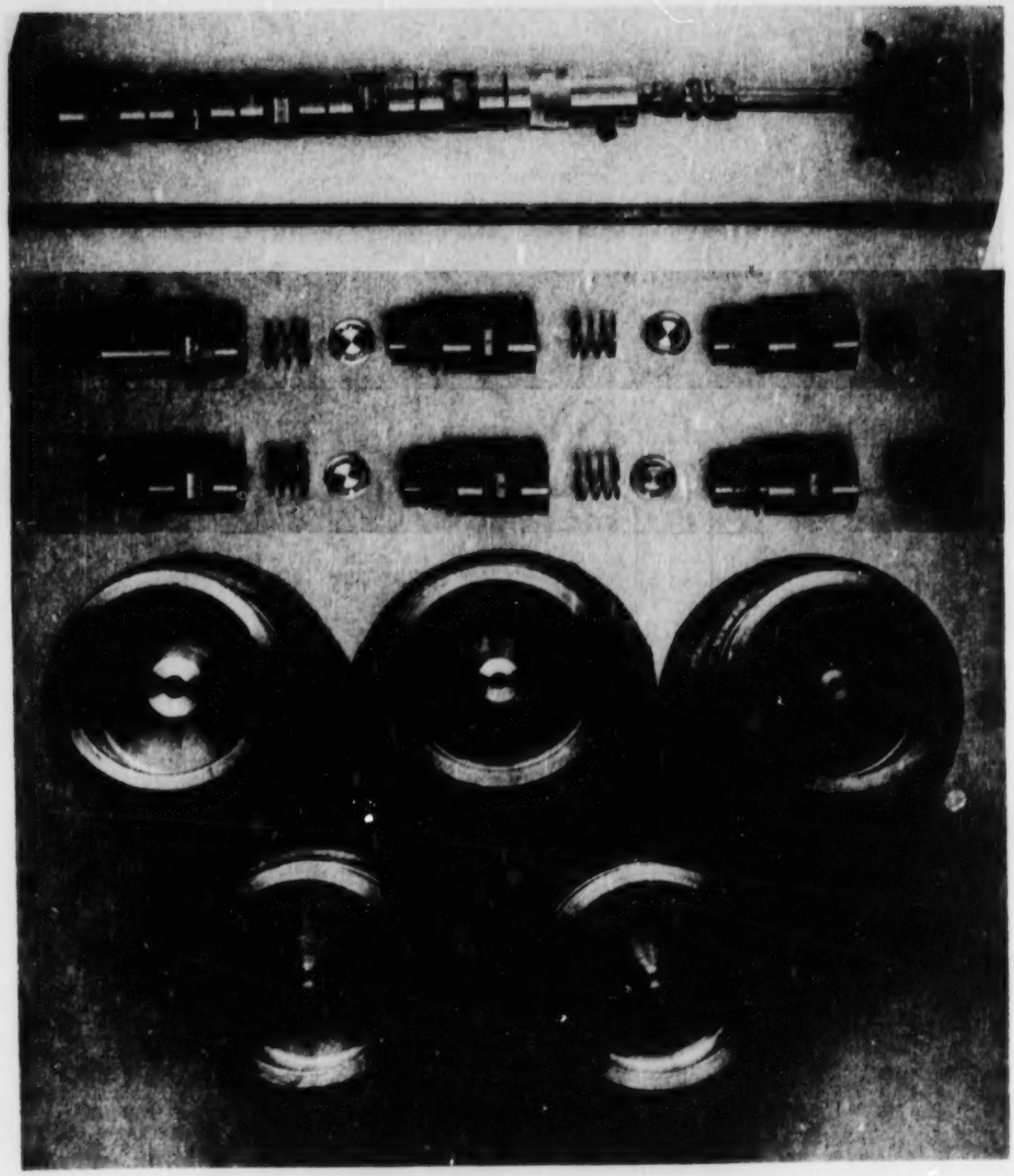


Figure D-2. Brink sampler showing assembled and disassembled sections.

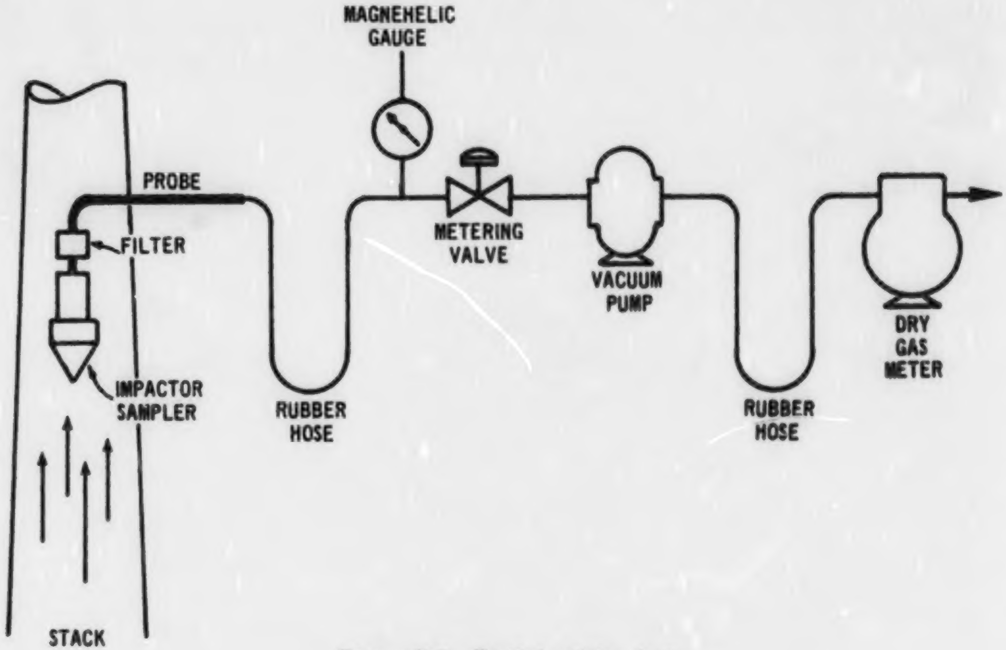

MAGNEHELIC GAUGE
PROBE
FILTER
METERING VALVE
VACUUM PUMP
DRY GAS METER
IMPACTOR SAMPLER
RUBBER HOSE
RUBBER HOSE
STACK

Figure D-3. Particle sizing train.

durations using the dry gas meter and for short durations using the pressure drop across the sampler.

The particle size tests made while measuring mass emission rates from furnaces A, C, D, E and G in the field testing program indicate that the particle size is largely submicron and that particle size distribution varies for different products. The mass median diameter (MMD) in microns is less for ferroalloys that contain silicon as a major component (for example, ferrochrome-silicon and silicomanganese) than it is for HC ferrochrome, which has a relatively low silicon content.

Size distributions are defined by two parameters: (1) the intercept of the curve with the 50 percent probability (mass mean particle diameter), and (2) the polydispersity factor or geometric standard deviation, defined as:

$$o = \frac{\text{diameter of particle at 50\% probability}}{\text{diameter of particle at 15.87\% probability}}$$

Figures D-4 through D-14 show graphical presentations of particle size test data, that is, log-probability plots of cumulative percent less than stated micron size versus the Dpc for each fraction collected by a cascade impactor. The intercept of these curves at 50 percent probability indicates that, on a weight basis, one-half of the particles are below the micron size shown at this intercept and one-half are above.

Table D-1 shows the particle size versus the collection efficiency of EPA-tested control equipment. It is interesting to note that the efficiency of scrubber G (Aeronetics scrubber system serving a silicomanganese furnace) becomes markedly less when the particle size is under 0.6 microns. It is also interesting to note that if an efficiency curve vs. particle size were to be drawn for the baghouse indicated in the table, there would be a slight dip in the curve at the particle size range between 0.3 to 1.0 microns. This drop in efficiency appears to be typical according to the article "Design and Performance of Modern Gas Cleaning Equipment" Journal of the Institute of Fuel, February 1956.

Tables D-2 through D-11 show the particulate emission losses in pounds per hour for various sources according to particle size ranges. These losses were calculated from the mass emission rates of particulates based on EPA tests and from Figures D-4 through D-14 of this appendix.

## Table D-1. PARTICLE SIZE VS. COLLECTION EFFICIENCY OF EPA-TESTED CONTROL EQUIPMENT (percent)

| Particle size range, microns | Control equipment | | | | | |
|---|---|---|---|---|---|---|
| | Scrubber[a] | | | Baghouse | Precipitator | Scrubber |
| | $C_1$ | $C_2$ | $C_3$ | D | E | G |
| 0 to 0.3 | 98.5 | 93.4 | 90.0[b] | 99.4 | 98.4 | NIL |
| 0.3 to 0.6 | 99.3 | 96.5 | 92.8 | 98.1 | 98.8 | 64 |
| 0.6 to 1.0 | 99.7 | 97.7 | 94.1 | 97.8 | 99.1 | 91 |
| 1.0 to 1.5 | 99.8 | 98.2 | 98.7 | 97.7 | 99.2 | 98 |
| +1.5 | 99.9 | 98.2 | 98.9 | 99.6 | 99.0 | 99 |
| Overall | 99.5 | 97.4 | 96.1 | 98.7 | 99.0 | 96 |

[a] Scrubber C tested at three pressure drops: C, at 57", $C_2$ at 47", and $C_3$ at 37" $H_2O$.

[b] Assumed. Actual calculations above 93%.

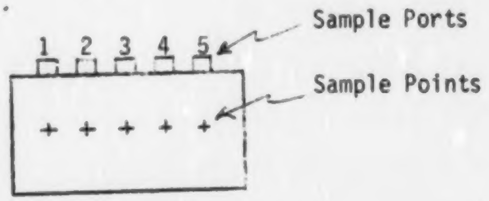
### Table D-2. PARTICULATE EMISSIONS BY PARTICLE SIZE FROM UNCONTROLLED FeCrSi FURNACE (lb/hr)

| Particle size range, microns | Sample no. | | |
|---|---|---|---|
| | A1 | A2 | A3 |
| 0 to 0.3 | 16 | 59 | 76 |
| 0.3 to 0.6 | 44 | 122 | 126 |
| 0.6 to 1.0 | 49 | 119 | 105 |
| 1.0 to 1.5 | 28 | 67 | 59 |
| +1.5 | 26 | 53 | 54 |
| Total, lb/hr | 163 | 420 | 420 |

Table D-3. PARTICULATE EMISSIONS BY PARTICLE SIZE FROM THE SCRUBBER INLET OF A SiMn FURNACE (lb/hr)

| Particle size, microns | Sample no.[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | C-1 | C-2 | C-3 | C-4 | C-5 | C-7 | Average |
| 0 to 0.3 | 223 | 484 | 55 | b | 290 | 545 | 319 |
| 0.3 to 0.6 | 427 | 502 | 83 | | 218 | 61 | 258 |
| 0.6 to 1.0 | 464 | 372 | 111 | | 181 | 48 | 235 |
| 1.0 to 1.5 | 316 | 202 | 120 | | 133 | 36 | 161 |
| +1.5 | 427 | 297 | 1477 | | 387 | 519 | 621 |
| Total, lb/hr | 1857 | 1857 | 1846 | 1611 | 1209 | 1209 | 1594 |

[a] Sample numbers C-1 and C-2 obtained at port 1, C-3 at port 2, C-4 at port 3, C-5 at port 4, and C-7 at port 5 (not simultaneously).



Cross section of inlet duct showing sampling ports.

[b] Data points are at the extremities of the graphs, either less than 15% or greater than 85% of stated size. Reliable particle sizes could therefore not be determined from these data.

## Table D-4. PARTICULATE EMISSIONS BY PARTICLE SIZE FROM SCRUBBER OUTLET OF A SiMn FURNACE
(lb/hr)

| Particle size, microns | Sample number and scrubber pressure drop, inches water | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | C-8 57" | C-9 57" | C-12 37" | C-13 47" | C-14 47" | C-15 37" | C-16 37" | C-17 37" |
| 0 to 0.1 | 1.65 | 1.59 | <0.30 | 2.00 | 10.6 | 1.5 | 5.6 | 1.5 |
| 0.1 to 0.2 | 1.32 | 2.35 | 0.40 | 2.00 | 15.2 | 5.7 | 8.5 | 5.0 |
| 0.2 to 0.3 | 0.99 | 1.68 | 2.12 | 1.42 | 10.6 | 9.2 | 10.6 | 7.8 |
| 0.3 to 0.4 | 0.66 | 1.01 | 3.54 | 1.06 | 7.1 | 8.5 | 7.1 | 7.1 |
| 0.4 to 0.5 | 0.58 | 0.59 | 4.24 | 0.83 | 5.0 | 7.1 | 7.1 | 7.1 |
| 0.5 to 0.6 | 0.41 | 0.42 | 4.24 | 0.59 | 3.5 | 5.7 | 5.0 | 7.1 |
| 0.6 to 0.7 | 0.33 | 0.25 | 3.54 | 0.47 | 3.5 | 5.0 | 4.2 | 5.0 |
| 0.7 to 0.8 | 0.25 | 0.17 | 3.18 | 0.47 | 2.1 | 3.5 | 3.5 | 4.2 |
| 0.8 to 0.9 | 0.25 | 0.08 | 2.48 | 0.35 | 2.1 | 3.5 | 3.0 | 3.5 |
| 0.9 to 1.0 | 0.16 | 0.04 | 2.12 | 0.24 | 1.5 | 3.5 | 2.1 | 3.5 |
| 1.0 to 1.2 | 0.25 | 0.03 | 3.18 | 0.47 | 2.1 | 3.5 | 3.5 | 5.0 |
| 1.2 to 1.5 | 0.33 | 0.02 | 2.80 | 0.47 | 2.8 | 4.9 | 3.5 | 4.9 |
| +1.5 | 1.08 | 0.16 | 3.28 | 1.43 | 4.5 | 9.0 | 6.9 | 8.9 |
| Total, lb/hr | 8.26 | 8.39 | 35.4 | 11.8 | 70.6 | 70.6 | 70.6 | 70.6 |

## Table D-5. PARTICULATE EMISSIONS BY PARTICLE SIZE FROM UNCONTROLLED TAPPING OF A SiMn FURNACE (lb/tap)

| Particle size range, microns | Sample no. | | | |
|---|---|---|---|---|
| | C-18 | C-19 | C-20 | C-21 |
| 0 to 0.3 | 4.2 | 11.7 | 4.2 | 12.2 |
| 0.3 to 0.6 | 6.4 | 9.5 | 4.8 | 9.5 |
| 0.6 to 1.0 | 6.9 | 8.0 | 5.3 | 7.4 |
| 1.0 to 1.5 | 6.4 | 5.8 | 4.8 | 6.4 |
| 1.5 to 2.0 | 4.8 | 3.7 | 4.2 | 3.2 |
| 2.0 to 3.0 | 6.4 | 4.8 | 5.8 | 5.3 |
| 3.0 to 6.0 | 9.0 | 5.3 | 9.0 | 4.8 |
| 6.0 to 10.0 | 3.7 | 2.1 | 5.8 | 2.1 |
| +10 | 5.2 | 2.1 | 9.1 | 2.1 |
| Total lb/tap | 53.0[a] | 53.0[a] | 53.0[a] | 53.0[a] |

[a] Average tapping loss per tap based on 3 test runs.

## Table D-6. PARTICULATE EMISSIONS BY PARTICLE SIZE FROM A FeCrSi FURNACE AT INLET TO BAGHOUSE

(lb/hr)

| Particle size range, microns | Sample no. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | D-1 | D-2[a] | D-3[a] | D-4[b] | D-5[b] | D-6[c] | D-7[c] | D-8[d] | D-9[d] |
| 0 to 0.3 | 161 | 36 | 101 | 131 | 327 | 178 | 296 | 107 | 184 |
| 0.3 to 0.6 | 125 | 48 | 101 | 119 | 113 | 125 | 77 | 77 | 83 |
| 0.6 to 1.0 | 101 | 54 | 95 | 89 | 71 | 95 | 54 | 71 | 65 |
| 1.0 to 1.5 | 71 | 48 | 65 | 77 | 36 | 59 | 30 | 65 | 48 |
| + 1.5 | 136 | 408 | 232 | 178 | 47 | 137 | 137 | 274 | 214 |
| Total, lb/hr | 594 | 594 | 594 | 594 | 594 | 594 | 594 | 594 | 594 |

[a] Samples 0-2 and D-3 collected simultaneously between furnace taps.
[b] Samples D-4 and D-5 collected simultaneously during furnace tap.
[c] Samples D-6 and D-7 collected simultaneously during furnace tap.
[d] Samples D-8 and D-9 collected simultaneously between furnace taps.

### Table D-7. PARTICULATE EMISSIONS BY PARTCLE SIZE FROM BAGHOUSE EXHAUST ON FeCrSi FURNACE

(lb/hr)

| Particle size range, microns | D-10 | D-11 | D-13 | D-14 | D-15 | D-16[a] | D-17[a] |
|---|---|---|---|---|---|---|---|
| 0 to 0.1 | -- | -- | 0.56 | 0.28 | 1.88 | -- | 0.26 |
| 0.1 to 0.3 | < 0.55 | <0.66 | 1.78 | 1.31 | 1.88 | <0.70 | 1.30 |
| 0.3 to 0.6 | 1.43 | 1.65 | 2.35 | 1.88 | 1.41 | 2.08 | 1.83 |
| 0.6 to 1.0 | 1.87 | 2.10 | 1.41 | 1.69 | 0.94 | 2.43 | 1.56 |
| 1.0 to 1.5 | 1.65 | 1.76 | 1.03 | 1.22 | 0.66 | 1.56 | 1.21 |
| 1.5 to 2.0 | 1.32 | 1.54 | 0.66 | 0.85 | 0.47 | 0.87 | 0.78 |
| 2.0 to 3.0 | 0.66 | 1.32 | 0.85 | 0.94 | 0.56 | 0.70 | 0.70 |
| 3.0 to 6.0 | 1.76 | 1.43 | 0.75 | 0.85 | 0.75 | 0.26 | 0.78 |
| 6.0 to 10.0 | 0.66 | 0.44 | 0.38 | 0.28 | 0.28 | -- | 0.17 |
| +10 | 1.10 | 0.10 | 0.19 | 0.01 | 0.57 | -- | 0.11 |
| Total, lb/hr | 11.0 | 11.0 | 9.96 | 9.31 | 9.40 | 8.7[b] | 8.7[a] |

[a] D-16 and D-17 samples obtained simultaneously.

[b] Average of three test runs.

Table D-8. PARTICULATE EMISSIONS BY PARTICLE SIZE FROM HC FeCr FURNACE AT PRECIPITATOR INLET

(lb/hr)

| Particle size, microns | Sample no. | | | Average |
|---|---|---|---|---|
| | E-1 | E-2 | E-3 | |
| 0 to 0.3 | 159 | 83 | 138 | 126 |
| 0.3 to 0.6 | 125 | 97 | 207 | 143 |
| 0.6 to 1.0 | 114 | 180 | 221 | 172 |
| 1.0 to 1.5 | 102 | 194 | 193 | 163 |
| + 1.5 | 638 | 830 | 625 | 698 |
| Total, lb/hr | 1138 | 1384 | 1384 | 1302 |

Table D-9. PARTICULATE EMISSIONS BY PARTICLE SIZE FROM HC FeCr FURNACE AT PRECIPITATORS OUTLET

(lb/hr)

| Particle size, microns | Sample no. | | | | |
|---|---|---|---|---|---|
| | E-4 | E-5 | E-6 | E-7 | E-8 |
| 0 to 0.1 | 0.38 | 1.25 | 0.43 | 0.57 | 0.57 |
| 0.1 to 0.2 | 0.62 | 0.75 | 0.57 | 0.71 | 0.85 |
| 0.2 to 0.3 | 0.88 | 0.50 | 0.71 | 0.71 | 0.71 |
| 0.3 to 0.4 | 0.75 | 0.38 | 0.57 | 0.57 | 0.71 |
| 0.4 to 0.5 | 0.75 | 0.38 | 0.57 | 0.57 | 0.71 |
| 0.5 to 0.6 | 0.62 | 0.38 | 0.43 | 0.57 | 0.57 |
| 0.6 to 0.7 | 0.62 | 0.25 | 0.43 | 0.57 | 0.57 |
| 0.7 to 0.8 | 0.62 | 0.25 | 0.43 | 0.28 | 0.43 |
| 0.8 to 0.9 | 0.38 | 0.13 | 0.43 | 0.43 | 0.43 |
| 0.9 to 1.0 | 0.38 | 0.25 | 0.28 | 0.28 | 0.43 |
| 1.0 to 1.2 | 0.88 | 0.25 | 0.57 | 0.57 | 0.57 |
| 1.2 to 1.5 | 0.88 | 0.50 | 0.85 | 0.43 | 0.85 |
| + 1.5 | 4.74 | 7.23 | 7.93 | 7.94 | 6.80 |
| Total, lb/hr | 12.50 | 12.50 | 14.20 | 14.20 | 14.20 |

Table D-10. PARTICLE EMISSIONS BY PARTICLE SIZE FROM SiMn FURNACE AT AERONETICS SCRUBBING INLET

(lb/hr)

| Particle size, microns | Sample no. | | |
|---|---|---|---|
| | G-1 | G-2 | Average |
| 0 to 0.3 | 2 | 1 | 2 |
| 0.3 to 0.6 | 10 | 3 | 7 |
| 0.6 to 1.0 | 20 | 9 | 15 |
| 1.0 to 1.5 | 27 | 11 | 19 |
| +1.5 | 136 | 164 | 150 |
| Total, lb/hr | 195 | 188 | 193 |

## Table D-11. PARTICULATE EMISSIONS BY PARTICLE SIZE FROM SiMn FURNACE AT AERONETICS SCRUBBER OUTLET

(lb/hr)

| Particle size, microns | Sample no. | | |
|---|---|---|---|
| | G-3 | G-4 | G-5 |
| 0 to 0.1 | 0.18 | 0.03 | 3.59 |
| 0.1 to 0.2 | 0.53 | 0.09 | 3.09 |
| 0.2 to 0.3 | 0.76 | 0.58 | 1.73 |
| 0.3 to 0.4 | 0.76 | 1.05 | 1.11 |
| 0.4 to 0.5 | 0.70 | 1.23 | 0.74 |
| 0.5 to 0.6 | 0.53 | 0.93 | 0.49 |
| 0.6 to 0.7 | 0.41 | 0.76 | 0.37 |
| 0.7 to 0.8 | 0.35 | 0.41 | 0.25 |
| 0.8 to 0.9 | 0.29 | 0.29 | 0.25 |
| 0.9 to 1.0 | 0.18 | 0.18 | 0.12 |
| 1.0 to 1.2 | 0.35 | 0.18 | 0.25 |
| 1.2 to 1.5 | 0.29 | 0.09 | 0.12 |
| +1.5 | 0.50 | 0.01 | 0.27 |
| Total, lb/hr | 5.83 | 5.83 | 12.38 |

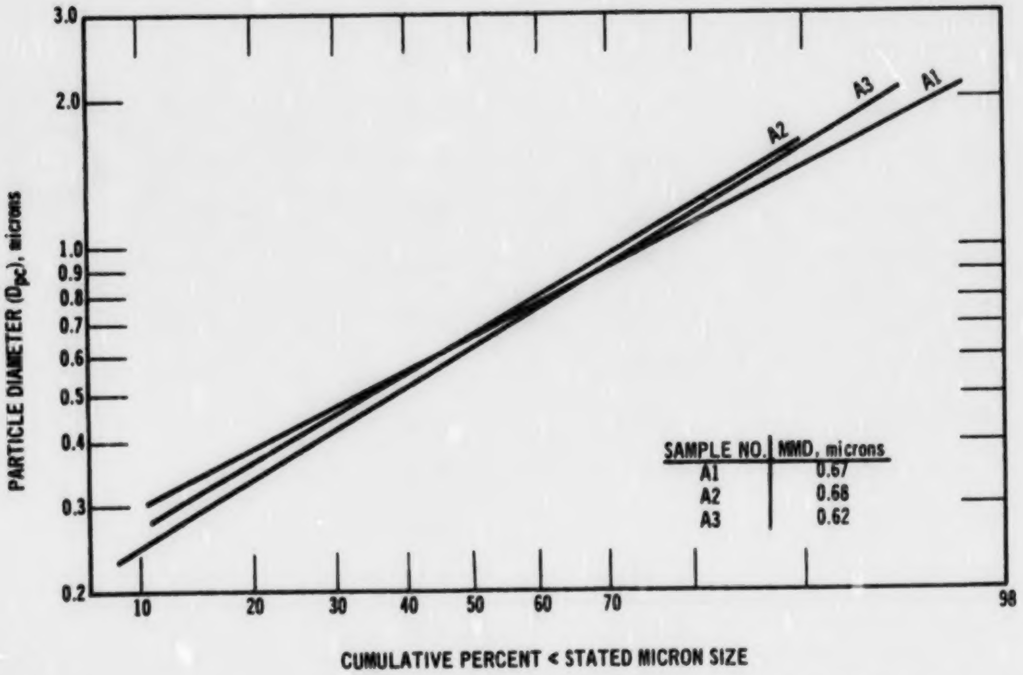


Figure D-4. Particle size distribution of uncontrolled fumes from a FeCrSi furnace.

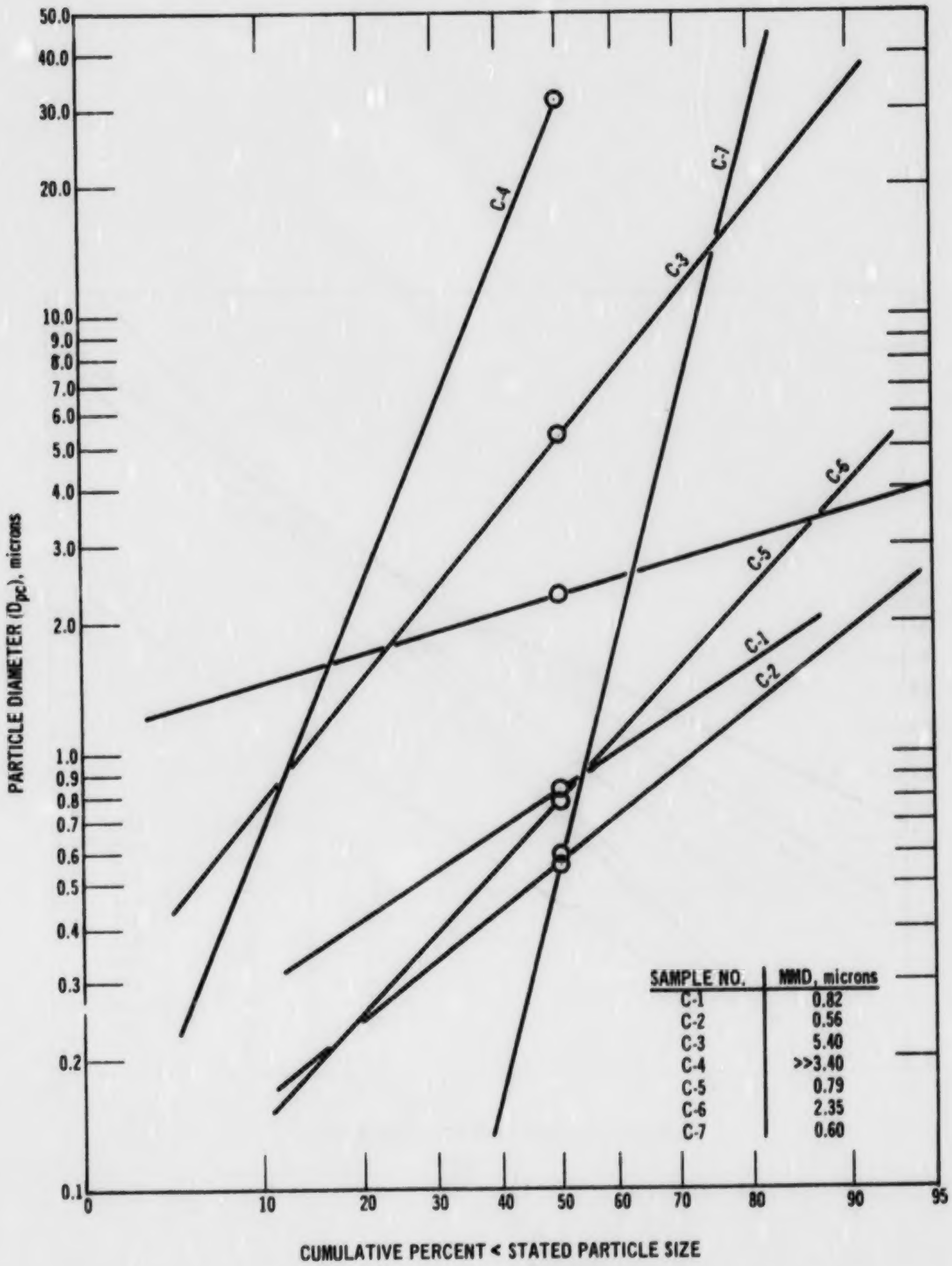
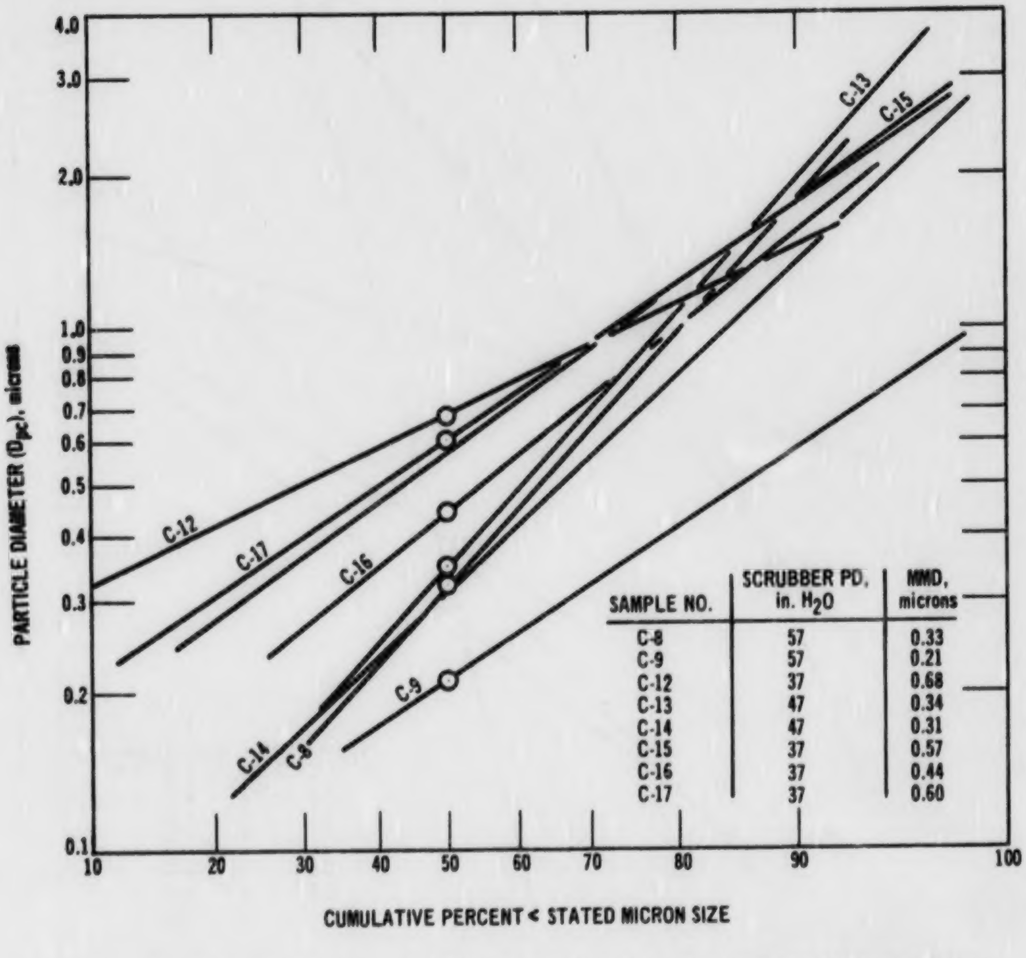


Figure D-5. Particle size distribution of SiMn fumes entering a scrubber serving an open furnace.



| SAMPLE NO. | SCRUBBER PD, in. $H_2O$ | MMD, microns |
|---|---|---|
| C-8 | 57 | 0.33 |
| C-9 | 57 | 0.21 |
| C-12 | 37 | 0.68 |
| C-13 | 47 | 0.34 |
| C-14 | 47 | 0.31 |
| C-15 | 37 | 0.57 |
| C-16 | 37 | 0.44 |
| C-17 | 37 | 0.60 |

Figure D-6. Particle size distribution of SiMn fumes from a scrubber serving an open furnace.

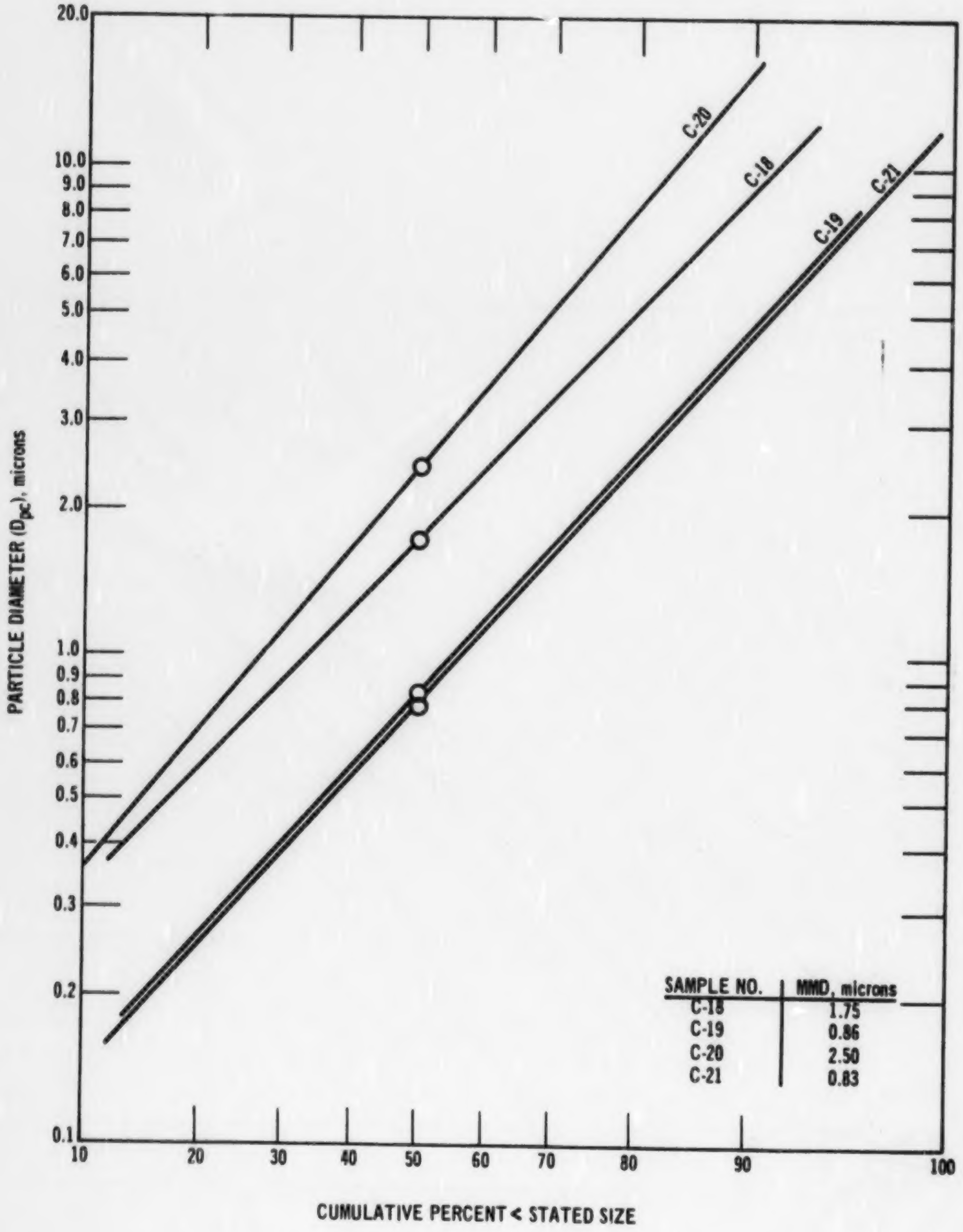
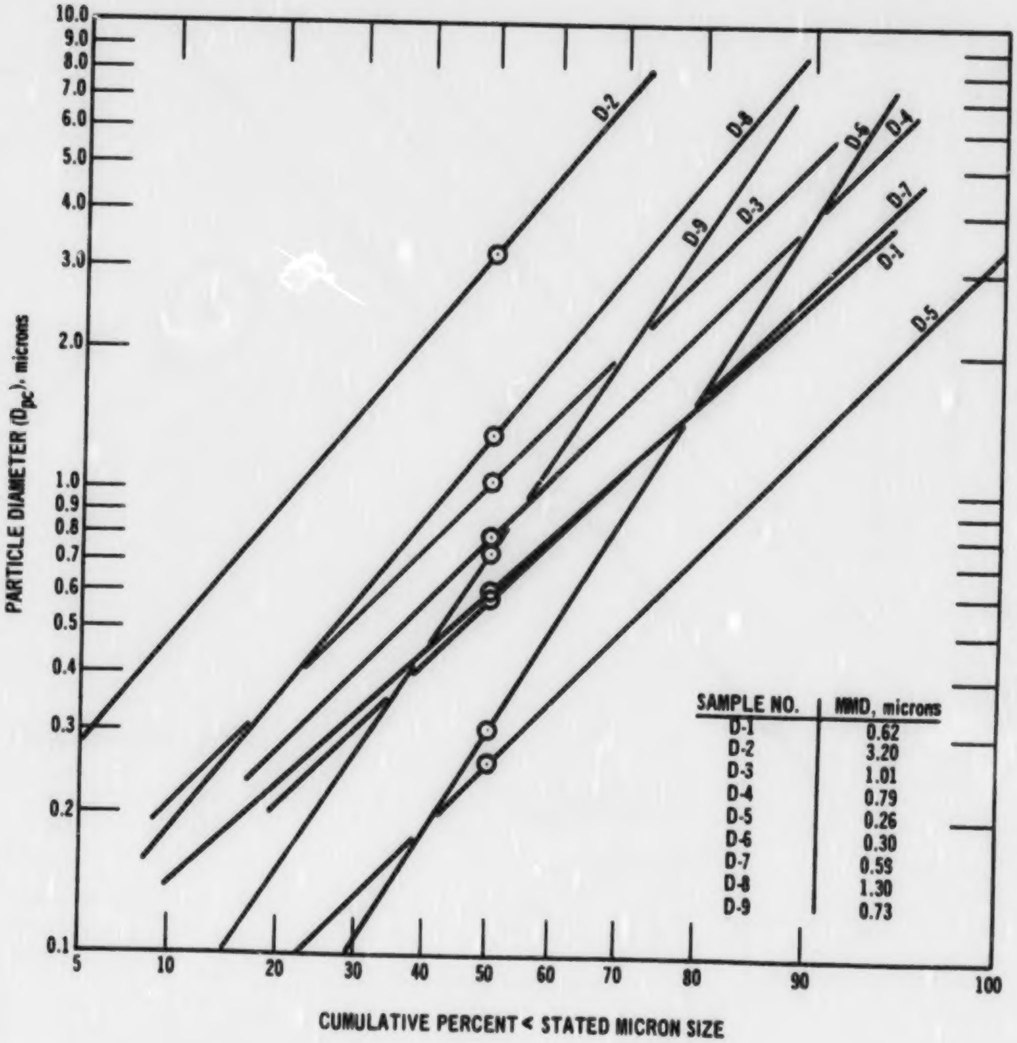
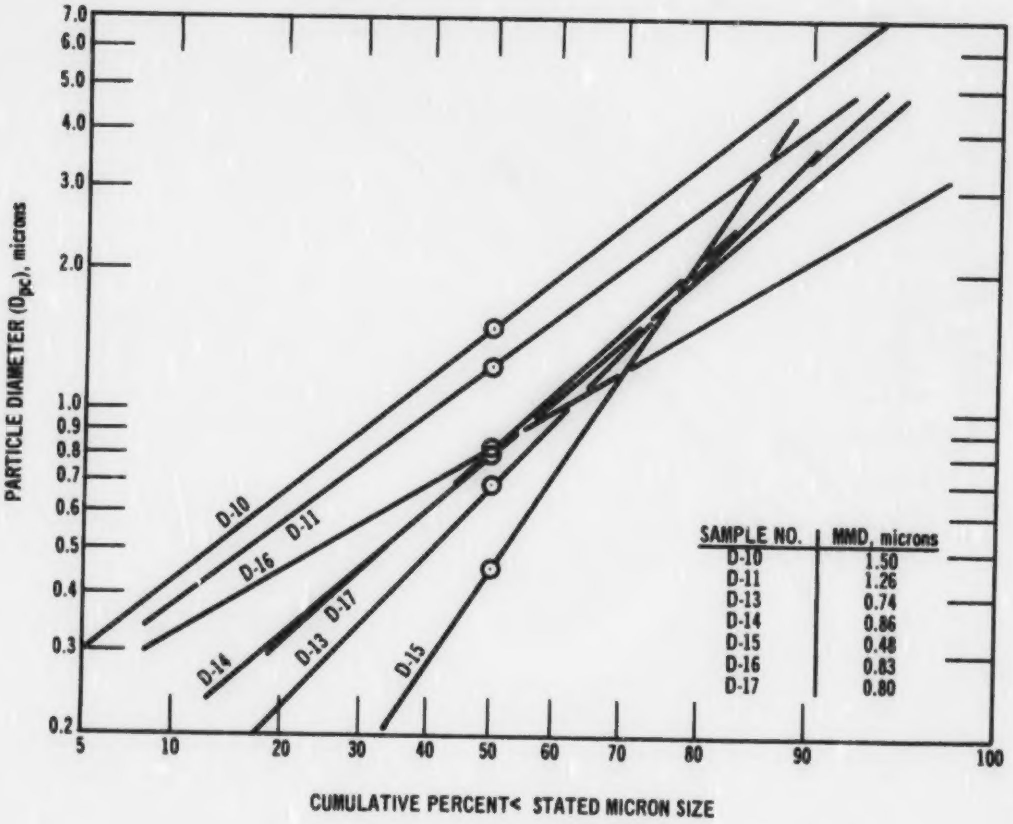


Figure D-7. Particle size distribution of uncontrolled tapping fumes from SiMn furnace.



| SAMPLE NO. | MMD, microns |
|---|---|
| D-1 | 0.62 |
| D-2 | 3.20 |
| D-3 | 1.01 |
| D-4 | 0.79 |
| D-5 | 0.26 |
| D-6 | 0.30 |
| D-7 | 0.59 |
| D-8 | 1.30 |
| D-9 | 0.73 |

Figure D-8. Particle size distribution of FeCrSi fumes entering a baghouse.



| SAMPLE NO. | MMD, microns |
|---|---|
| D-10 | 1.50 |
| D-11 | 1.26 |
| D-13 | 0.74 |
| D-14 | 0.86 |
| D-15 | 0.48 |
| D-16 | 0.83 |
| D-17 | 0.80 |

Figure D-9. Particle size distribution of FeCrSi fumes from a baghouse serving an open furnace.

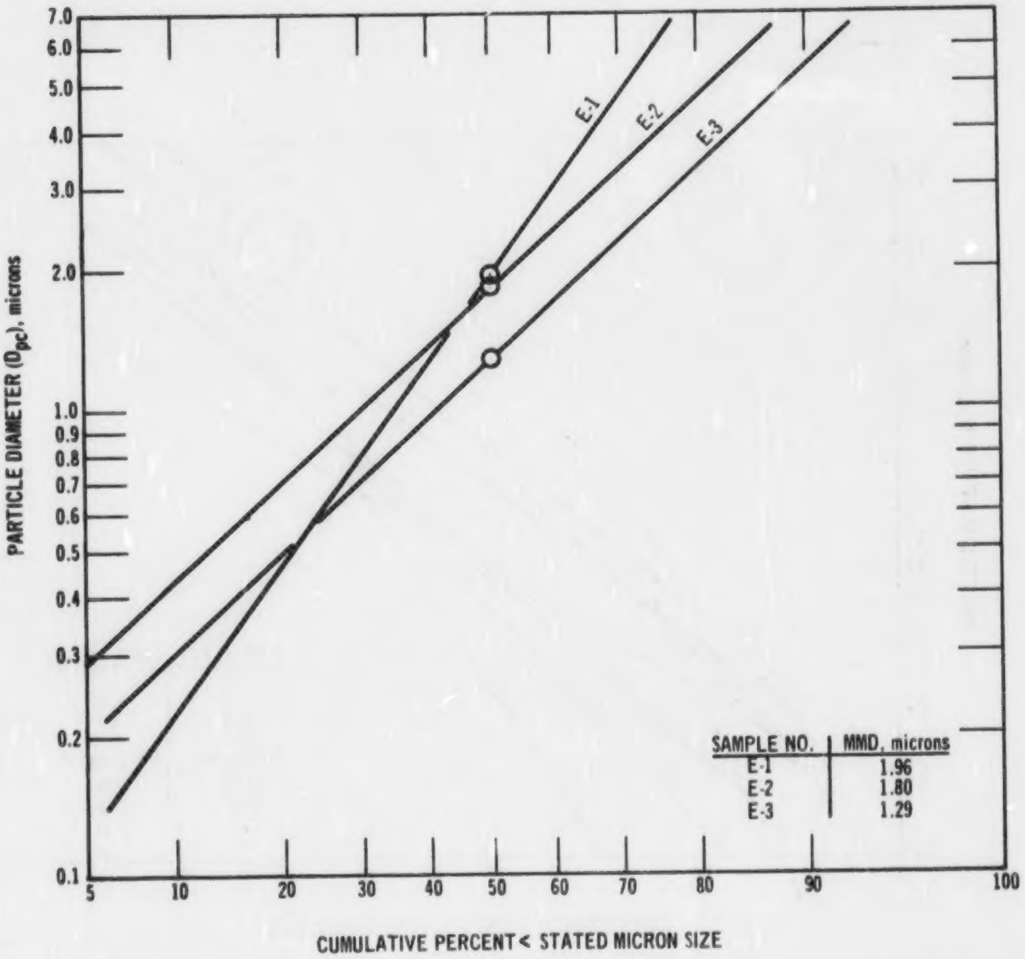


Figure D-10. Particle size distribution of (HC)FeCr fumes entering a precipitator serving an open furnace.

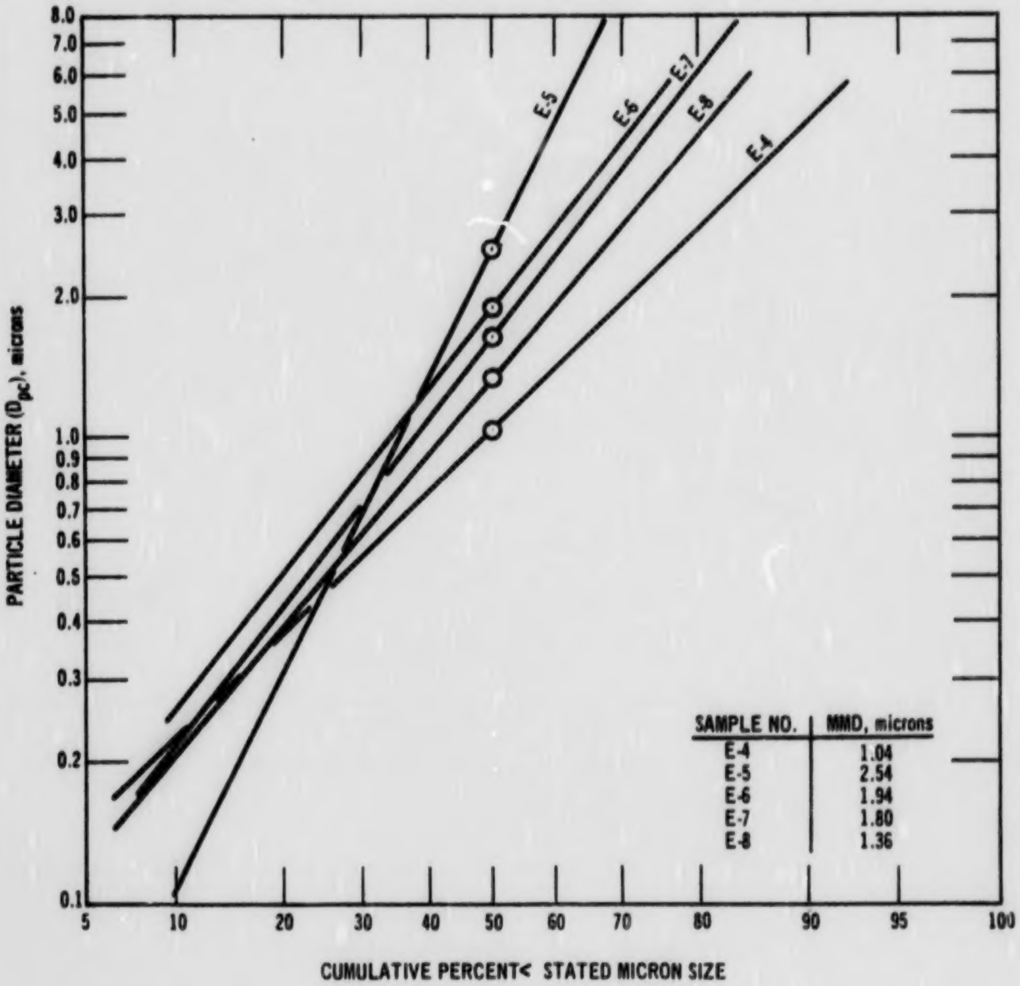


Figure D-11. Particle size distribution of (HC)FeCr fumes from a precipitator serving an open furnace.

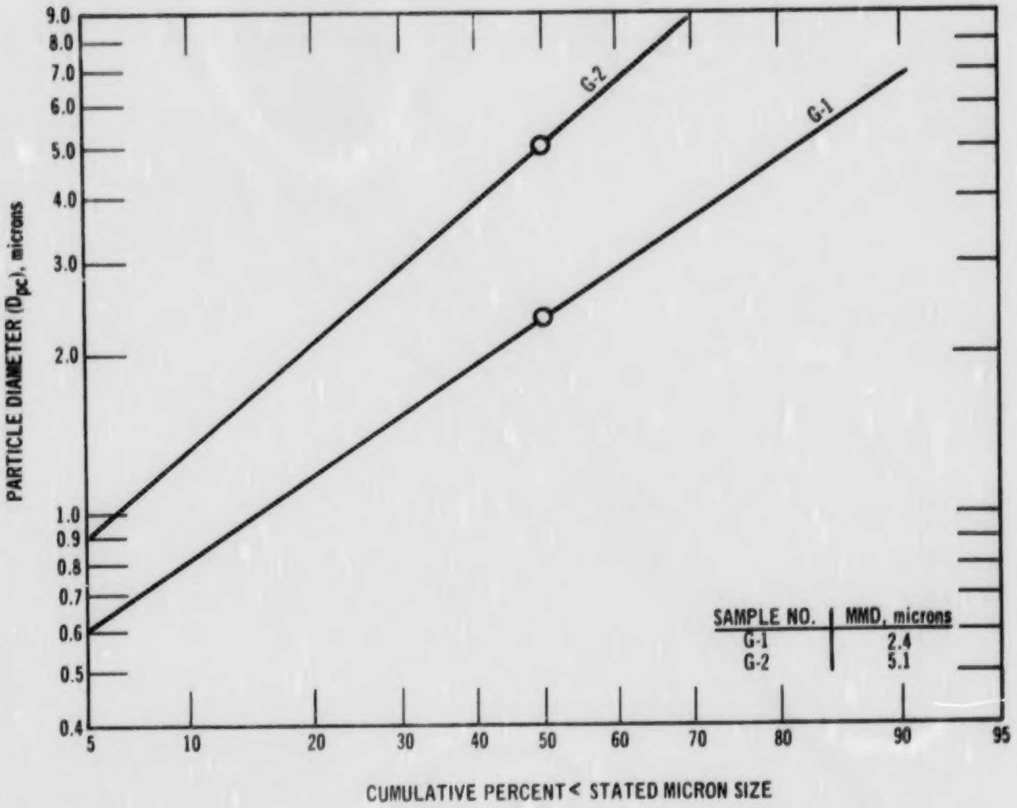


Figure D-12. Particle size distribution of SiMn fumes entering a scrubber serving an open furnace.

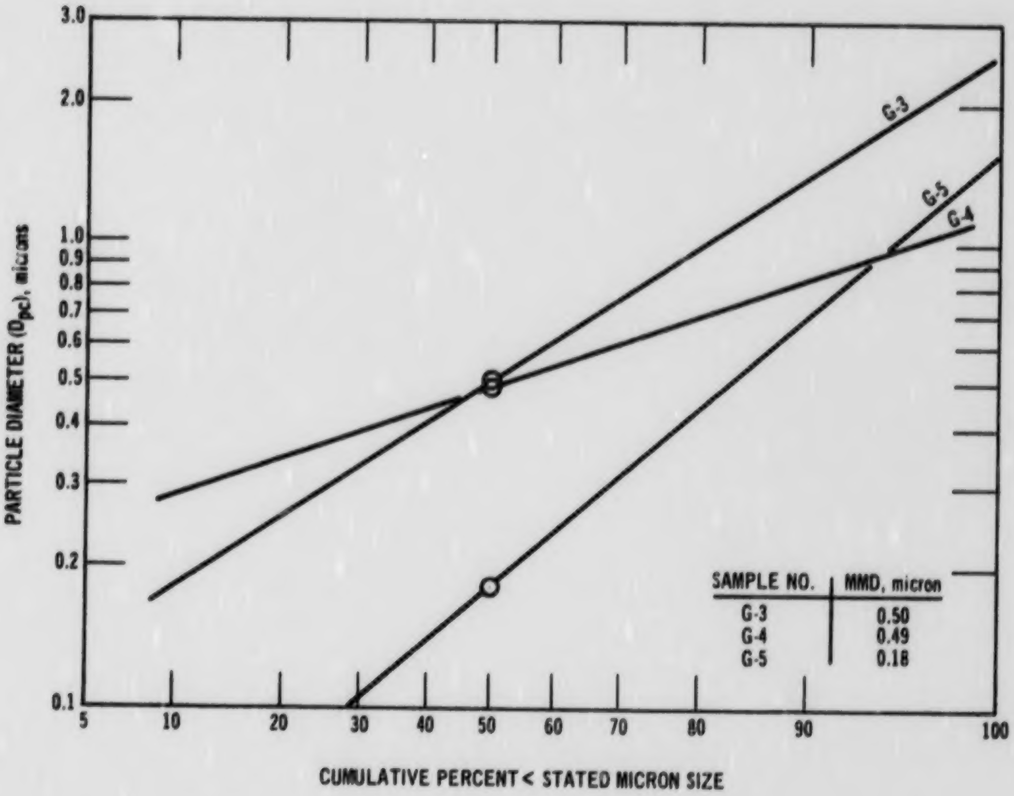


Figure D-13. Particle size distribution of SiMn fumes from a scrubber serving an open furnace.

# E-I. CHEMICAL ANALYSES OF PARTICULATE EMISSIONS
# FROM
# FERROALLOY SMELTING OPERATIONS

## 1. INTRODUCTION

Chemical analyses were made on particulate samples collected by the EPA sampling train using the EPA sampling method 5 described in Appendix C of this report. The samples were obtained from 10 ferroalloy furnaces, and were sent to private contractors for analysis. Metal analyses were made by either the optical emission spectrography or the atomic absorption method. In a few instances, the same samples underwent the electron beam microanalysis. A total of 87 separate metal analyses covering 25 test runs were made. These are reported as metals and not as metal oxides which appear in the samples.

Table E-1 shows the number and types of analyses made of the 10 furnaces tested. In addition to those shown in the table, analyses were made of the anions, $NH_4^+$, and water insolubles of the collected particulates from Furnaces D,H,K, and L.

Table E-1. NUMBER AND TYPES OF ANALYSES MADE OF TEN FURNACES SAMPLED

| Furnace | Number of EPA tests analyzed | Number of metal analyses made of EPA tests | Number of organic analyses made | Number of combustible analyses made | Number of metal analyses made of ore samples | Number of metal analyses made of solids in scrubber water | Number of metal analyses made of collected precip.dusts | Number of metal analyses made of slag |
|---|---|---|---|---|---|---|---|---|
| A | 2 | 12[a,b] | | | | | | |
| B | 2 | 2[a,b] | | | | | | |
| C | 4 | 6[c] | | | 2 (Mn ore)[d] | 7[d] | | 2[d] |
| D | 4 | 8[a,b] | | | 2 (Cr ore)[d] | | | |
| E | 2 | 2[b,c] | | | | | 1[d] | |
| F | 4 | 19[d] | | | | | | |
| G | 2 | 14[d] | | | | | | |
| H | 4 | 9[d] | 3 | 2 | | | | |
| K | 3 | 5[d] | 2 | 2 | | | | |
| L | 3 | 10[d] | 3 | 3 | | | | |

[a] Metal analyses made by atomic absorption and optical emission spectrography.

[b] Qualitative electron beam x-ray microanalyses.

[c] Metal analyses determined by atomic absorption method.

[d] Metal analyses determined by optical emission spectrography.

# E-II. CHEMICAL ANALYSIS OF EMISSIONS
# FROM
# A FERROCHROMESILICON FURNACE (A)
# AND A CHROME ORE/LIME MELT FURNACE (B)

## 1. INTRODUCTION

Particulate fumes and gaseous emissions are generated during the smelting and pouring of a commercially important class of ferroalloy materials called reactive metals. The particulate portion of these emissions has been collected on glass fiber filters, strategically placed in the air stream of an exhaust system. Fourteen such filters from Furnaces A and B were analyzed by microscope, X-ray diffraction, atomic absorption, electron beam X-ray microanalysis, and optical emission spectroscopy.

The analytical results are presented in the following sections where it is shown that the particulate specimens from the two furnaces are distinctly different from the standpoints of chemical composition and crystallographic structure. The samples from Furnace A consist principally of non-crystalline fused silica ($SiO_2$) with impurities. Impurities present in concentrations>1 weight percent are Mg, Cr, and Zn in decreasing order. In contrast, the samples from Furnace B contain crystalline material with the inverse spinel structure such as typified by $Fe_3O_4$. Instead of consisting mostly of $SiO_2$ as seen for the Furnace A specimens, the specimens from Furnace B consist of chromium, silicon, magnesium, iron, and zinc all in the 4 to 18 weight percent range along with chemically combined oxygen. This is, the specimens from Furnace B consist of metal oxides.

## 2. TEST RESULTS

### 2.1 Optical Examination

The specimens were examined at magnifications up to 100X. Figure E-1 shows Specimen 25W-1 and shows the manner in which all specimens were divided for individual analysis. The specimens from Furnace B were yellow-brown and distinctly different from the gray-colored Furnace A specimens.

### 2.2 X-Ray Diffraction Analysis

X-ray diffraction occurs when a crystalline substance is exposed to a beam of X-rays. The angle between the diffracted beam and the incident beam is always 2$\theta$, or twice the angle of incidence. By using monochromatic X-rays of wavelength $\lambda$, the interplanar spacing d of various planes in a crystal can be found by using Bragg's Law, $\lambda = 2d \sin \theta$. An electronic detector or photographic film is used to record $\theta$ angles and the intensities of the diffracted beams. Every crystalline substance has an unique X-ray pattern comprised of many $\theta$ angles (usually converted to d-spacings) and associated intensity values. Over 22,000 X-ray diffraction patterns have been published to date.

The diffraction samples were prepared by removing the powders from the individual filters, thoroughly mixing each powder manually in a plastic container with a wooden tongue depressor, and pressing into 1/2-inch diameter pellets under 80,000 psi. This method of specimen removal from the quartz ($SiO_2$) filter in no way disturbed the filter. No filter particles mixed with the specimens removed. In fact, a small quantity of powder remained on the filter after removal of the specimens. These pellets were analyzed on a G.E. XRD-5 X-ray unit. The instrumental settings used are listed in Table E-2.

The diffraction patterns from all samples were weak; therefore, a chromium tube was used as a source of X-rays in order to reduce background radiation due to X-ray fluorescence. The use of the chromium X-ray tube and pulse height analysis maximized the signal/noise ratio.

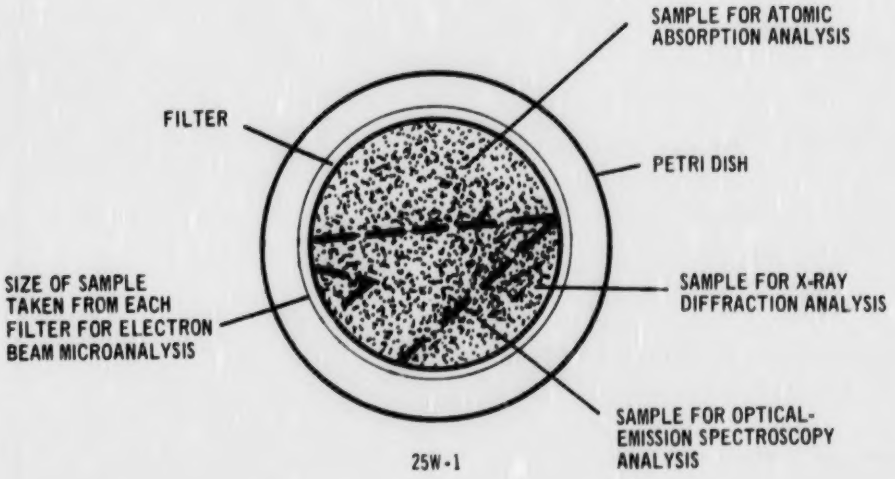

SAMPLE FOR ATOMIC ABSORPTION ANALYSIS
FILTER
PETRI DISH
SIZE OF SAMPLE TAKEN FROM EACH FILTER FOR ELECTRON BEAM MICROANALYSIS
SAMPLE FOR X-RAY DIFFRACTION ANALYSIS
SAMPLE FOR OPTICAL-EMISSION SPECTROSCOPY ANALYSIS
25W-1

Figure E-1. Drawing of condensate from ferrochrome operation showing area analyzed.

## TABLE E-2.
## X-RAY DIFFRACTOMETER SETTINGS

X-ray Source: Chromium Tube; 50KVP, 20 ma, no filter

Beam Slit: 1°

Soller Slit: Medium Resolution

Exit Slit: 0.1°

Table Speed: 2°/Min; Chart Speed 2"/min.

Detector: Flow proportional

Scale: Linear 100

Pulse Height Selector: $E1 = 2V$ with Gain x 16.
$\Delta E = 6V$

The diffraction results are summarized in Figure E-2 which shows the sample identification, and the d-spacings and relative intensities of the diffracted beams. These patterns were then compared with tables of known diffraction patterns.[*]

The X-ray results can be summarized as follows:

1. All specimens were largely non-crystalline as evidenced by an absence of a diffraction pattern or very weak diffuse patterns with very few lines. No X-ray diffraction patterns were obtained from Specimens 25W-1, 25W-2, 25E-1, and 25E-2; they were completely non-crystalline.[**]

2. Another eight samples had weak patterns, but the patterns could not be correlated in a meaningful way with any known pattern from the diffraction file. In a few instances, a force-fit might have been possible but the choices were hydrated crystals such as $Ca_3Al_8(PO_4)_8(OH)_6 \cdot 15H_2O$. It seemed unlikely that a highly hydrated and complex crystal would have formed during the few microseconds available for emissions to condense from the gaseous high temperature effluent. These eight patterns were, therefore, classified as unknown.

3. Recognizable patterns were obtained from both specimens from Furnace B. The patterns belong to the naturally occurring class of compounds called spinels.[***] It was not possible to positively tell which particular spinel oxide was present but the best fit to the X-ray data include:

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[*] Joint Committee on Powder Diffraction Standards, Powder Diffraction File, Swarthmore, Pennsylvania, 1969.

[**] The specimen numbers designate the Furnace, A or B, and duct, west or east, from which specimens, 1 or 2, were taken simultaneously. For example, specimen 25W-1 is Sample #1 taken from the west (W) duct of Furnace A. Specimen 25E-1 was taken from the east duct of Furnace A at the same time specimen 25W-1 was taken.

[***] The spinel group includes a large number of oxides of the general formula $AB_2O_4$. The more familiar members of the spinel group are $MgAl_2O_4$, $ZnFe_2O_4$, $CdFe_2O_4$, $FeAl_2O_4$, $CoAl_2O_4$, $NiAl_2O_4$, $MnAl_2O_4$, and $ZnAl_2O_4$. Inverse spinels have the same X-ray pattern, are more common in nature, and include $FeO \cdot Fe_2O_3$ also written as $Fe_3O_4$.

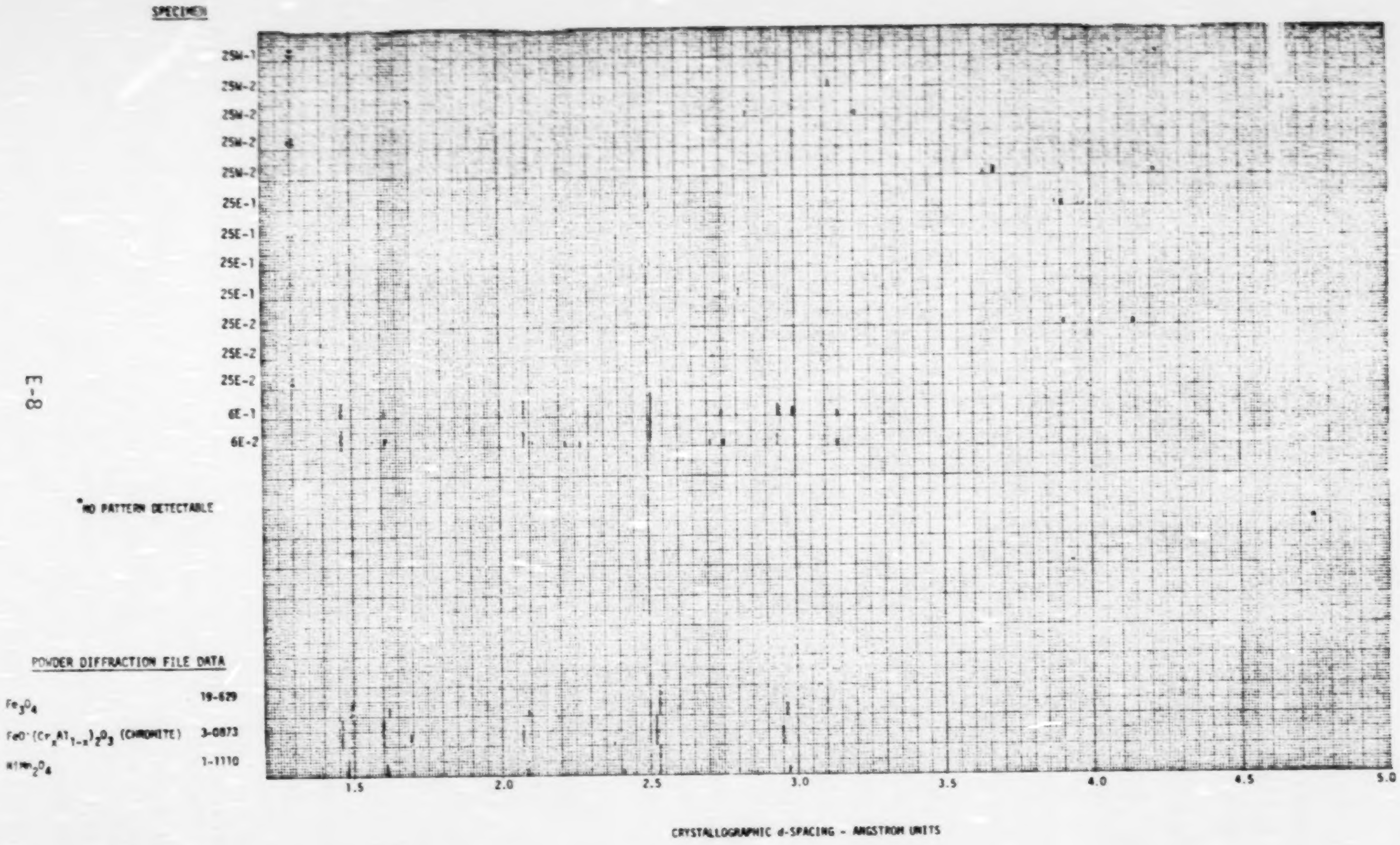

Figure E-2. Summary of X-ray diffraction data.

Chromite: $FeO \cdot [Cr_x Al_{1-x}]_2 O_3$ $0.64 < x < 1$

and

Magnetite: $FeO \cdot Fe_2O_3$

4. The eight unidentified weak patterns were scrutinized to see if any possibility exists that the compounds reported previously might be present. No evidence was found to indicate the presence of CaO, SiC, FeSi, $FeSi_2$, MnO, or any of the numerous crystallographic allotropes of either SiC or $SiO_2$ (quartz).

### 2.3 Atomic Absorption Analysis

Atomic Absorption (A.A.) means that a cloud of atoms in the un-ionized and unexcited state is capable of absorbing radiation at wavelengths that are specific in nature and characteristic of the element in consideration. The atomic absorption spectrophotometer used in these analyses consists of a series of lamps which emit the spectra of the elements determined, a gas burner to produce an atomic vapor of the sample, a monochromator to isolate the wavelengths of interest, a detector to monitor the change of absorption due to the specimen, and a readout meter to visualize this change in absorption.

The sample pellet previously used for the X-ray diffraction analysis was carefully pulverized, weighed into a tared 150-ml beaker, and extracted for two hours with hot aqua regia (4 ml HCl + 16 ml $HNO_3$).* The resulting solution was then filtered and the residue washed several times with cold water. The filtrate from the above extraction was concentrated on a low-heat hot plate, transferred to a 25-ml volumetric flask, and the elemental concentrations determined by Atomic Absorption Spectroscopy (A.A.). The residues from the above extractions were ignited in a muffle furnace at 900°C and fused with 0.4 g $Na_2CO_3$. The resulting fusion product was dissolved in water, made acid with $H_2SO_4$, and taken to dryness on a high-heat hot plate. The resulting residue was taken up to 100 ml of dilute acid (1 ml $H_2SO_4$ in 100 ml $H_2O$) and filtered. The $SiO_2$ content was determined gravimetrically by igniting and weighing the filtered solids residue.** The filtrate was concentrated on a low-heat hot plate, transferred to a 100-ml volumetric flask, and the elemental concentration determined by A.A.

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* R. J. Thompson, G. B. Morgan and L. J. Purdue, "Analysis of Selected Elements in Atmospheric Particulate Matter by Atomic Absorption," Atomic Absorption NEWS Letter, Vol. 9, No. 3, 1970.

** N. H. Furman Ed., Standard Methods of Chemical Analysis, 6th Edition, Vol. 1, D. Van Nostrand Co., Inc., Princeton, New Jersey, pp. 950-957, 1962.

The individual elemental concentrations obtained from the aqua regia leach and the filtrate from the $Na_2CO_3$ fusion were then summed for each sample; these results are compiled in Table E-3. Samples 6E-1 and 6E-2 were found to be insoluble in the $Na_2CO_3$ flux and as a consequence of this, it was not possible initially to obtain $SiO_2$ or further elemental analysis on these two samples using the above method. These two samples were found to be soluble in a potassium pyrosulfate flux. The samples were, therefore, fused with approximately 0.5 gram of potassium pyrosulfate, and the resultant fused samples were then dissolved in dilute HCl. The solution was then filtered; the filtrate made up to 100 cc volume, and subsequently analyzed by Atomic Absorption Spectroscopy (A.A.). The residue on the filter paper was then ignited in a muffle furnace at 900°C and the residue back weighed as $SiO_2$. The results of these analyses were added to the results found for the acid extracted portion of the sample, and are tabulated in Table E-3. Since the optical-emission spectroscopy analyses discussed later showed that Specimens 6E-1 and 6E-2 contained considerable quantities of calcium, A.A. analyses for calcium were run on these two specimens also. The instrumental parameters used for each element are listed in Table E-4. Nitrous oxide-acetylene flames were used for Cr and Mg to eliminate inter-element interferences.* Because of the small amount of sample collected (30-120 mg) and the desirability of determining the toxic elements (Mn, Cd, Pb, As, Hg, Be) in low concentration levels, it was found necessary to use the entire sample for each of the above analyses.

The choice of these elements was based on the combined considerations of (i) expected presence in condensate, (ii) toxicity, and (iii) availability of atomic absorption lamps. The results are summarized as follows:

1. The samples from Furnace A invariably contain at least 66 wt% $SiO_2$ with an average value of 73.6 wt%. In contrast, the specimens from B contained only ~6 wt% $SiO_2$ as found in a supplemental optical-emission analysis. The $SiO_2$ did not come from the filter paper because the sample was removed from the quartz ($SiO_2$) paper prior to analysis.

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* Walter Slavin, Atomic Absorption Spectroscopy, Interscience Publishers, New York, New York, pp 79-189, 1968.

# TABLE E-3.

## METALS ANALYSIS OF PARTICULATES (FURNACES A & B)

| Sample # | Ca | Cr | Mn | Cd | Pb | Hg[a] | Be | V | Mg | Fe | Zn | Al | $SiO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25W-1[b] | -- | 2.11 | 0.059 | 0.002 | 0.0013 | <0.05 | <0.001 | <0.03 | 4.7 | 0.45 | 1.68 | <0.02 | 72.1 |
| 25W-2 | -- | 0.74 | 0.065 | <0.0003 | <0.0008 | " | " | " | 7.8 | 0.18 | 0.43 | 0.18 | 81.4 |
| 25W-2 | -- | 1.68 | 0.081 | " | 0.0012 | " | " | " | 7.2 | 0.37 | 1.56 | 0.079 | 74.4 |
| 25W-2 | -- | 0.94 | 0.056 | 0.0007 | <0.0008 | " | " | " | 6.5 | 0.30 | 0.44 | 0.050 | 76.3 |
| 25W-2 | -- | 1.22 | 0.028 | <0.0003 | " | " | " | " | 7.1 | 0.44 | 0.39 | <0.02 | 72.9 |
| 25E-1 | -- | 2.08 | 0.104 | 0.0005 | 0.0008 | " | " | " | 7.6 | 0.43 | 0.84 | 0.11 | 70.5 |
| 25E-1 | -- | 1.66 | 0.079 | " | <0.0008 | " | " | " | 11.3 | 0.40 | 0.50 | 0.11 | 67.5 |
| 25E-1 | -- | 1.82 | 0.084 | 0.0004 | " | " | " | " | 11.9 | 0.39 | 0.52 | 0.16 | 66.6 |
| 25E-2 | -- | 1.15 | 0.064 | <0.0003 | " | " | " | " | 8.2 | 0.22 | 0.78 | 0.14 | 75.7 |
| 25E-2 | -- | 1.86 | 0.087 | " | " | " | " | " | 6.7 | 0.42 | 0.53 | 0.21 | 77.1 |
| 25E-2 | -- | 0.96 | 0.071 | " | " | " | " | " | 8.1 | 0.24 | 0.42 | 0.095 | 75.2 |
| 25E-2[c] | -- | 0.68 | 0.037 | 0.0005 | " | " | " | " | 5.1 | 0.27 | 0.30 | 0.024 | SPILLED |
| 6E-1[d] | 10.6 | 12.4 | 0.107 | 0.003 | 0.0067 | " | " | " | 7.6 | 4.9 | 3.9 | 0.59 | 12.2 |
| 6E-2 | 10.7 | 18.1 | 0.102 | 0.0018 | 0.0043 | " | " | " | 7.3 | 5.4 | 1.6 | 0.50 | 8.3 |

[a] Only the acid leach sample was analyzed. Hg would be lost during fusion.

[b] Sample designations preceded by 25 are from Furnace A (FeCrSi furnace).

[c] Part of the sample was lost due to a spill. The results here, therefore, represent only what was present in the acid leach.

[d] Sample designations preceded by 6 are from Furnace B (chrome ore/lime melt furnace).

## TABLE E-4.

## INSTRUMENTAL PARAMETERS

| ELEMENT | WAVELENGTH (Å) | FUEL OXIDIZER SYSTEM | SLIT WIDTH (Å) | HOLLOW CATHODE CURRENT (MA) |
|---|---|---|---|---|
| Cr | 3579 | $N_2O$ acetylene | 2 | 10 |
| Mn | 2801 | air acetylene | 2 | 10 |
| Cd | 2288 | air acetylene | 7 | 4 |
| Pb | 2833 | air acetylene | 7 | 4 |
| Hg | 2537 | air acetylene | 7 | 4 |
| Be | 2348 | $N_2O$ acetylene | 7 | 12 |
| V | 3184 | $N_2O$ acetylene | 7 | 15 |
| Mg | 2852 | $N_2O$ acetylene | 7 | 4 |
| Fe | 2483 | air acetylene | 2 | 12 |
| Zn | 2138 | air acetylene | 7 | 8 |
| Al | 3093 | $N_2O$ acetylene | 7 | 13 |
| Ca | 4227 | $N_2O$ acetylene | 7 | 8 |

2. The chromium content ranged from 0.68 to 2.08 wt% from Furnace A and the average value was 1.3 wt%. The value from Furnace B is much higher at 7.2 wt%.

3. The average manganese content was 0.067 wt% in Furnace A and 0.062 wt% in B. The values are virtually the same.

4. The magnesium content varied considerably among different samples. It was highest, 11.6 wt%, in the two 25E-1 specimens. These specimens also had the lowest $SiO_2$ levels (67.5 and 66.6 wt%) from among the samples from Furnace A.

5. The iron content in Furnace B was a full factor of 10 higher than in Furnace A. The average values in Furnace B and A are 3.75 and 0.34 wt%, respectively.

6. The zinc content in Furnace A varied from 0.30 to 1.68 wt% with an average of 1.04 wt%. The corresponding value for Furnace B is 2.20 wt%.

7. The average aluminum content from Furnace A was 0.10 wt% and, hence, lower than the 0.545 wt% found in the two samples from Furnace B.

8. Mercury, beryllium, and vanadium, all toxic elements, were below the detectability limits of 0.05 wt%, 0.001 wt%, and 0.03 wt%, respectively.

9. The cadmium levels from Furnace A varied from below 0.0003 wt% to 0.002 wt%. The condensate from Furnace B contained an average of 0.0024 wt% cadmium which was somewhat higher than that for Furnace A but still relatively low. Cadmium is a toxic element.

10. Calcium analyses of Specimens 6E-1 and 6E-2 from Furnace B were decided on only after it was seen from the optical-emission spectroscopy results that the calcium levels were very high compared to the Furnace A specimens. The A.A. analyses for

calcium yielded 10.6 wt% and 10.7 wt% for the two specimens. Since the A.A. technique is more exacting than the optical-emission technique, it is the A.A. calcium values which should be considered as being the true calcium concentrations in the Furnace B specimens.

11. The total concentration of elements from Furnace A samples is virtually 100% when all the metal values are converted to equivalent oxide percentages.* This means that all the major elements in the emissions from this furnace were detected and, in addition, a few minor but toxic elements (V, Hg, Be, Cd) were also detected.

12. The total concentration of elements from Furnace B after conversion to equivalent oxide percentages is 70%, a somewhat less satisfactory mass balance situation than for Furnace A. This lack-of-closure should not be taken to signify the presence of an additional but undetected element. No additional element of any consequence was detected in either the electron microprobe or optical-emission techniques. It is concluded that all the major elements are accounted for in Table E-3 and that the lack-of-closure in samples from Furnace B is due to errors associated with the extreme difficulty encountered in dissolving the samples.

## 2.4 Electron Beam X-Ray Microanalysis

The electron microprobe is an advanced piece of equipment which uses a small beam of electrons to produce characteristic X-ray emissions from a sample volume with a radius of ~1 micron. Curved crystal X-ray spectrometers are used to analyze the resultant characteristic X-ray spectra. In these analyses, the electron beam was defocused to a diameter of 200 microns (0.008 inch) to cover a larger segment of the sample.

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* Equivalent oxide percentages are obtained by multiplying the weight percent metal in Table E-3 by the ratio Mo/Mm where Mo is the molecular weight of the metal oxide and Mm is that of the metal. The oxide formulae were taken to be $Al_2O_3$, ZnO, $Fe_3O_4$, MgO, $A_2O_3$, and CaO. Thus for Ca, the equivalent oxide percentage is 10.65 x (40+16)/40. Justification for this conversion is based on electron microprobe results.

The electron beam impinged in vacuum upon the untouched sample surface as shown in Figure E-1. An examination was made of the complex spectrum of X-rays given off by the specimen under electron beam excitation, and it was found that the entire spectrum could be identified uniquely on the basis of the elements shown in Table E-4. All portions of the X-ray spectrum in the wavelength range 1-100A covering all elements except H, He, Li, and Be were taken into account.

The silicon and oxygen signals did not originate from the silica filters although the latter were present in the electron microprobe chamber. The electron beam penetrated about 2 microns (and absolutely no more than 20 microns) into the sample from the top surface. The total sample thickness was about 0.02 inch (~500 microns). Thus, the silica filter material was ~500 microns away from the effective sensing depth of the electron beam.

The major outcome of the electron microprobe analyses was that the main elements were identified for the atomic absorption analysis already discussed. Thus, Fe, Cr, Si, Al, Ca, Mg, and Zn were found on the untouched samples and were, therefore, selected along with other elements for A.A. analyses.

A second outcome of the electron microprobe analyses was the detection of oxygen at roughly the 50% level in the samples from both furnaces. This means that the metals are present as oxides and is the basis for the conversion of the metal percent values in Table E-3 to equivalent oxide percents.* The 50% oxygen value was strictly applicable only to the top 2-20 microns of the untouched samples where the analyses were made. However, it was assumed that the sample was essentially a mixture of oxides throughout its depth. Such an assumption seemed reasonable when the source of the samples was taken into account.

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* The 50% value was obtained in a $10^{-6}$ torr vacuum. Thus oxygen was not an occluded atmospheric gas but was present as an oxide.

## Table E-5. ELECTRON BEAM X-RAY MICROANALYSIS RESULTS FROM QUALITATIVE ANALYSES

| Sample | Elements Positively Identified in X-ray Spectra |
|---|---|
| 25E-1[a] | Fe, Cr, O, Si, Al, Ca, Mg, Zn, Na, Ba, K, -, -, - |
| 25E-2[a] | Fe, Cr, O, Si, Al, Ca, Mg, -, -, -, -, Ni, -, - |
| 6E-2[b] | Fe, Cr, O, Si, Al, Ca, Mg, Zn, Na, -, -, Ni, Cl, S |

---

[a] Ferrochromesilicon furnace (Furnace A).

[b] Chrome ore/lime melt furnace (Furnace B).

The concentrations are not given in the electron microprobe table (Table E-5) because, although the elements shown were present throughout the depth of the samples, their concentrations (particularly the metals) varied with depth (i.e., the samples were non-uniform). Thus, the atomic absorption analyses were used to determine the quantitative analyses on properly composited samples while the electron microprobe qualitatively identified the elements.

## 2.5 Optical-Emission Spectroscopy

Optical-emission spectroscopy or arc-spark spectroscopy consists of electrical excitation of the electrons of the elements in the sample. When the electrons return to their ground state, light is emitted. The emitted light is passed through a prism or diffraction grating to separate it into its component wavelengths. The spectrum is then analyzed electronically or optically on a photographic plate. Each line occurring at a definite wavelength position on the spectrum designates a specific element, and the intensity of light at that wavelength is proportional to the quantity of that element present.

Portions of the samples were subjected to optical-emission analyses to provide (i) a check on the analytical procedures (particularly the lack-of-closure in the atomic absorption analyses from Furnace B ), and (ii) a more sensitive approach to trace element analysis than that provided by electron beam X-ray microanalysis. The spark emission results for the major elements agreed well with the atomic absorption and electron beam results and, in addition, identified numerous trace impurities not found in the other approaches. The results are compiled in Table E-6.

Table E-6. OPTICAL EMISSION ANALYSES (WT%)

| Sample No. | Si | Mg | Al | Fe | Cr | Zn | Ca | Na | Ni | Mn | V | Cu | Co | Ti | B | Pb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25W-1[a] | 40 | 4 | 2 | 1 | 1 | 1 | 0.2 | 0.8 | 0.005 | 0.05 | <0.005 | <0.001 | 0.001 | 0.001 | 0.005 | 0.03 |
| 25W-2 | 40 | 6 | 2 | 1 | 1 | 0.2 | 0.1 | 0.4 | 0.005 | 0.05 | <0.005 | <0.001 | 0.001 | 0.001 | 0.005 | 0.01 |
| 25W-2 | 40 | 6 | 2 | 1 | 1 | 0.4 | 0.2 | 0.6 | 0.005 | 0.05 | <0.005 | <0.001 | 0.001 | 0.002 | 0.005 | 0.01 |
| 25W-2 | 40 | 6 | 2 | 1 | 1 | 0.4 | 0.1 | 0.4 | 0.005 | 0.05 | <0.005 | <0.001 | 0.001 | 0.001 | 0.005 | 0.01 |
| 25W-2 | 40 | 6 | 2 | 1 | 1 | 0.4 | 0.2 | 0.6 | 0.005 | 0.05 | <0.005 | <0.001 | 0.001 | 0.001 | 0.005 | 0.01 |
| 25E-1 | 40 | 6 | 2 | 1 | 1 | 1 | 0.2 | 0.8 | 0.005 | 0.05 | <0.005 | <0.001 | 0.001 | 0.001 | 0.01 | 0.01 |
| 25E-1 | 40 | 10 | 2 | 1 | 1 | 0.4 | 0.2 | 0.8 | 0.005 | 0.05 | <0.005 | <0.001 | 0.001 | 0.002 | 0.01 | 0.01 |
| 25E-1 | 40 | 6 | 2 | 0.5 | 1 | 0.4 | 0.2 | 0.8 | 0.005 | 0.05 | <0.005 | <0.001 | 0.001 | 0.002 | 0.02 | 0.01 |
| 25E-1 | 40 | 8 | 3 | 0.5 | 1 | 0.4 | 0.2 | 0.4 | 0.005 | 0.05 | <0.005 | <0.001 | 0.001 | 0.002 | 0.005 | 0.01 |
| 25E-2 | 40 | 6 | 2 | 1 | 1 | 0.4 | 0.2 | 0.4 | 0.005 | 0.05 | <0.005 | <0.001 | 0.001 | 0.002 | 0.005 | 0.01 |
| 25E-2 | 40 | 6 | 2 | 1 | 1 | 0.4 | 0.1 | 0.6 | 0.005 | 0.05 | <0.005 | <0.001 | 0.001 | 0.002 | 0.005 | 0.01 |
| 25E-2 | 40 | 4 | 2 | 1 | 1 | 0.4 | 0.2 | 0.4 | 0.005 | 0.05 | <0.005 | <0.001 | 0.001 | 0.001 | 0.005 | 0.01 |
| 6E-1[b] | 3 | 10 | 3 | 10 | 10 | 2 | 20 | 1.0 | 0.3 | 0.05 | <0.03 | <0.001 | 0.001 | 0.001 | 0.02 | 0.01 |
| 6E-2 | 3 | 10 | 2 | 10 | 10 | 3 | 20 | 1.0 | 0.3 | 0.05 | <0.03 | <0.001 | 0.03 | 0.03 | 0.005 | 0.05 |

Note: Values of Major Elements ± 30% of Reported Value.

Elements listed below not detected. The limits of detection are given.

| | |
|---|---|
| Hg | 200 PPM |
| As | 200 PPM |
| Te | 200 PPM |
| Sb | 50 PPM |
| Be | 2 PPM |
| Cd | 100 PPM |

[a] Sample designations preceded by 25 are from a ferrochromesilicon furnace (Furnace A).

[b] Sample designations preceded by 6 are from a chrome ore/lime melt furnace (Furnace B).

# III. CHEMICAL ANALYSIS OF EMISSIONS
# FROM
# A SILICOMANGANESE FURNACE

## 1. INTRODUCTION

Particulate fumes and gaseous emissions are generated during the smelting and pouring of a commercially important class of ferroalloy materials called reactive metals. The particulate portion of these emissions has been collected on glass fiber filters, strategically placed in the air stream of an exhaust system. Six such filter samples taken from a scrubber serving a SiMn furnace and an uncontrolled tapping station were analyzed by microscope, qualitative electron beam X-ray microanalysis, and atomic absorption. The analytical results are presented in the following sections. Sample specimen designations preceded by MIE are filter samples collected at the scrubber outlet; those preceded by WTE and ETE are samples collected at the tapping station.

## 2. TEST RESULTS

### 2.1 Optical Examination

The specimens were examined at magnifications up to 30X. The particulate matter could be seen intimately mixed with the quartz filter fibers, and it was obvious that the particulate matter could not be physically separated from the filter pad upon which it had been collected. Under tungsten filament the specimens appeared as follows:M1E-6 (light gray), M1E-7 (dark gray), M1E-12 (yellow-brown) and ETE-2 (partly dark brown, partly light brown).

## 2.2 Electron Beam X-Ray Microanalysis

The electron microprobe is an advanced piece of equipment which uses a small beam of electrons to produce characteristic X-ray emissions from a sample volume with a radius of ~1 micron. Curved crystal X-ray spectrometers are used to analyze the resultant characteristic X-ray spectra. In these analyses, the electron beam was defocused to a diameter of 150 microns (0.006 inch) to cover a relatively large area of each specimen and thereby obtain data which would be representative of the entire sample. The electron beam impinged in vacuum upon the untouched sample surface. An examination was made of the complex spectrum of X-rays given off by the specimen under electron beam excitation, and it was found that the entire spectrum could be identified uniquely on the basis of the elements shown in Table E-7.All portions of the X-ray spectrum in the wavelength range 1-100A covering all elements except H, He, Li, and Be were taken into account.

The analyses were conducted on small portions of the filter pads which were not later digested for the atomic absorption analyses. The small samples for electron probe analyses are still intact. The qualitative analysis results are summarized in Table E-7.Several points seem germane:

1. The major elements are manganese, magnesium, calcium, and potassium. The silicon signal could have come from either the filter pad or from the particulate matter. The fibers of the pad were visible in the optical microscope which is attached to the electron probe.

2. Distinct signals, equivalent to several weight percent, were found for sulfur, chlorine, carbon, sodium, and potassium.

3. The presence of sodium and chlorine frequently suggests salt and could have come from handling with bare hands. However, it must be stated that the filters were not handled with bare hands during the chemical analysis effort.

## 2.3 Atomic Absorption Analyses

Atomic Absorption (A.A.) means that a cloud of atoms in the un-ionized and unexcited state is capable of absorbing radiation at wavelengths that are specific in nature and characteristic of the element in consideration. The atomic absorption spectrophotometer used in these analyses consists of a series of lamps which emit the spectra of the elements determined, a gas burner to produce an atomic vapor of the sample, a monochromator to isolate the wavelengths of interest, a detector to monitor the change of absorption due to the specimen, and a readout meter to visualize this change in absorption.

The filters with samples were weighed, and the sample weights calculated by subtracting the tare weights written on the outside of the Petri dish sample containers from the total weights. Specimen identifications were as follows: M1E-6, M1E-7, M1E-12, and a composited specimen consisting of filters WTE-3, ETE-1, and ETE-2.

Table E-7. QUALITATIVE ELECTRON BEAM X-RAY MICROANALYSES

| Specimen No. | Cr | Mn | Mg | Fe | Al | Ca | Ba | Na | K | Zn | Cl | S | Si | C | Source |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M1E-6 | - | H | M | L | T | H | - | M | H | L | H | M | M | L-M | Scrubber Exhaust |
| M1E-7 | - | H | H | L | M | H | T | H | H | T | H | H | H | L-M | Scrubber Exhaust |
| M1E-12 | - | H | H | L | H | H | M | H | H | - | L | L | H | L-M | Scrubber Exhaust |
| ETE-2 | T | H | H | L | H | H | M | H | H | T | L | M | H | L-M | Tapping |

KEY: H = greater than 20 wt%

M = 10-20 wt%

L = 1-10 wt%

T = less than 1 wt%

NOTE: Sample ETE-2 was later composited with WTE-2 and ETE-1 in the atomic absorption analyses. The compositing operation in this particular case involved digesting three filter pads, with their particulate matter, in one common acid solution. The microprobe analyses were performed on a portion of ETE-2 that was not digested.

The filters (both pad and particulate) were extracted for 2 hours with 50 mls of 1:1 $H_2SO_4$; this solution was decanted and saved. The filters were then extracted for 2 hours with a boiling dilute Aqua Regia solution.* This solution was then combined with the $H_2SO_4$ solution, filtered, taken to constant volume in a volumetric flask, and analyzed by A.A. The instrumental parameters used for the individual elements are given in Table E-8 and the results of the A.A.** analyses are shown in Table E-9.

The A.A. results are normalized to compensate for the portion removed for electron beam X-ray microanalyses. Silica ($SiO_2$) analyses were not performed since the entire $SiO_2$ filter pad with the intimately mixed specimen was digested in acid in each case. In order to determine if the acid digestion process chemically attacks the $SiO_2$ filter, an unused filter will be exposed to the digestion process and A.A. analyses run on a blank to determine background concentrations. A remote possibility exists that some K or Na could have come from the filter material if it is not pure $SiO_2$.

Note also that in Table E-9 only one speciman (M1E-6) adds up to 100%. The other specimens most likely consist of metal oxides or a mixture of metals and metal oxides; oxygen and silicon are therefore the likely missing chemical components needed to bring the totals in all four cases to 100%.

A comparison of these results with the results reported for Furnace A immediately brings to light certain differences between the two emissions. The emissions from Furnace C contain, in general, less chromium but more manganese, sodium, potassium, chlorine, and, to be particularly noted, sulfur, than Furnace A emissions.

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* R. J. Thompson, G. B. Morgan, and L. J. Purdue, "Analysis of Selected Elements in Atmospheric Particulate Matter by Atomic Absorption", Atomic Absorption NEWS Letter, Volume 9, No. 3, 1970

** Walter Slavin, Atomic Absorption Spectroscopy, Interscience Publishers, New York, New York, pp 79-189, 1968.

Table E-8. Instrumental Parameters

| Element | Wavelength (Å) | Fuel Oxidizer System | Slit Width (Å) | Hollow Cathode Current (Ma) |
|---|---|---|---|---|
| Cr | 3579 | Air-Acetylene | 2 | 10 |
| Mn | 2801 | Air-Acetylene | 2 | 10 |
| Mg | 2852 | $N_2O$-Acetylene | 7 | 4 |
| Fe | 2483 | Air-Acetylene | 2 | 12 |
| Al | 3093 | $N_2O$-Acetylene | 7 | 13 |
| Ca | 4227 | $N_2O$-Acetylene | 7 | 8 |
| Ba | 5536 | $N_2O$-Acetylene | 7 | 7 |
| Na | 5890 | Air-Acetylene | 20 | 10 |
| K | 7665 | Air-Acetylene | 20 | 10 |
| Zn | 2139 | Air-Acetylene | 7 | 8 |

Table E-9. Atomic Absorption Analysis Results Elemental Concentration (Wt%)

| Specimen No. | Cr | Mn | Mg | Fe | Al | Ca | Ba | Na | K | Zn | Total (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MIE-6[a] | 0.09 | 27.6 | 2.3 | 1.0 | 0.6 | 0.6 | - | 21.3 | 37.3 | 1.9 | 94.2 |
| MIE-7[a] | 0.04 | 7.6 | 1.2 | 0.2 | 0.6 | 0.9 | - | 44.4 | 18.2 | 0.2 | 73.3 |
| MIE-12[a] | 0.09 | 7.7 | 1.2 | 0.3 | 0.9 | 0.4 | - | 37.8 | 14.8 | <0.01 | 63.2 |
| Composite[b] (WTE-3, ETE-1, and ETE-2) | 0.1 | 21.8 | 0.6 | 1.0 | 0.7 | 0.4 | - | <0.05 | 6.0 | 0.3 | 30.9 |

NOTE: Silicon analyses not performed.

SPECIAL NOTE: The values have been corrected, at the last minute, to account for contributions from the collector pad.

[a] MIE-6, MIE-7 and MIE-12 are filter samples collected at scrubber outlet serving a SiMn furnace.

[b] WTE-3, ETE-1 and ETE-2 are filter samples collected at uncontrolled exhaust systems serving the furnace tapping operation.

FURNACE C

ENVIRONMENTAL PROTECTION AGENCY
Research Triangle Park, North Carolina 27711

*Reply to Attn of:*

*Date:* 11-17-71

*Subject:* Analysis of Samples for Mercury

*To:* K. W. Grimley, Division of Applied Technology

THRU: R. E. Lee, Jr., Chief, SSFAB RL

1. Origin: Furnace C

2. Date collected: 7/31 - 8/3/71
   Date analyzed: 11/10/71

3. These seven samples of scrubber exit water were analyzed for mercury using flameless atomic absorption.

4. Tests were run on both the clear liquid and the liquid and sediment. There was no mercury detected in any of the samples run.

5 The lower detectable limit is ~.008 ug Hg/g.

Kathryn E. MacLeod

Kathryn E. MacLeod
Source Sample and Fuels
Analysis Branch, DAS

cc: R. Neligan
A. Altshuller
J. McGinnity
D. Shearer
D. von Lehmden
D. Slaughter
R. Atherton
W. Kelly
F. Wilshire

## Table E-10. OPTICAL EMISSION SPECTROGRAPHY[a]

| | Hg | Be | Cd | As | V | Mn | Ni | Sb | Cr | Zn | Cu | Pb | Se | B | Li | Ag | Sn | Fe | Sr | Na | K | Ca | Si | Mg | Al | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -S1 Scrubber Water Test A-2 | <0.01 | <0.02 | < 0.8 | < 2. | <0.6 | 830. | < 0.2 | < 0.8 | 0.8 | < 2. | 0.3 | 3. | -- | 0.8 | 8. | <0.02 | < 0.8 | 8. | 0.8 | 830. | 1660. | 83. | 415. | 250. | 83. | -- |
| -S2 Scrubber Water Test A-3 | <0.01 | <0.02 | < 0.7 | < 2. | <0.5 | 740. | 0.3 | < 0.7 | 0.7 | 2. | 0.4 | 4. | -- | 1. | 4. | <0.02 | < 0.7 | 37. | 0.7 | 370. | 1110. | 150. | 370. | 150. | 75. | -- |
| -S3 Scrubber Water Test B-1 | <0.01 | <0.01 | < 0.7 | < 2. | <0.6 | 660. | < 0.1 | < 0.7 | 0.7 | < 1. | 0.3 | 3. | -- | 0.4 | 3. | <0.01 | < 0.7 | 20. | 0.7 | 660. | 1000. | 120. | 330. | 230. | 66. | -- |
| -S4 Scrubber Water Test B-2 | <0.01 | <0.02 | < 0.7 | < 2. | <0.5 | 740. | < 0.1 | < 0.7 | 0.7 | 2. | 0.7 | 5. | -- | 0.7 | 4. | <0.02 | < 0.7 | 50. | 0.7 | 740. | 1110. | 150. | 370. | 150. | 75 | -- |
| -S5 Scrubber Water Test B-3 | <0.01 | <0.01 | < 0.5 | < 1. | 0.3 | 500. | 0.5 | < 0.5 | 3. | 1. | 1. | 4. | -- | 0.5 | 3. | <0.01 | < 0.5 | 50. | 1. | 250. | 750. | 200. | 250. | 175. | 175. | -- |
| -S6 Scrubber Water Test C-1 | <0.01 | <0.01 | < 0.5 | < 1. | <0.3 | 550. | 0.2 | < 0.5 | 1. | 1. | 0.5 | 3. | -- | 0.5 | 4. | <0.01 | < 0.5 | 17. | 0.5 | 550. | 825. | 175. | 250. | 175. | 55. | -- |
| -S7 Scrubber Water Test C-2 | <0.01 | <0.02 | < 0.9 | < 2. | <0.6 | 930. | 0.6 | < 0.9 | 2. | 2. | 1. | 5. | -- | 1. | 7. | <0.02 | < 0.9 | 65. | 2. | 470. | 930. | 370. | 930. | 220. | 190. | -- |

---

[a] Results in ppm of as-received sample except where otherwise designated.

ENVIRONMENTAL PROTECTION AGENCY

*Reply to Attn of:*

*Date:* September 10, 19

*Subject:* Ore and Slag Samples - Furnace C

*To:* Dr. R. E. Lee
Source Sample and Fuels Analytical Branch
Division of Atmospheric Surveillance

1. Origin: Samples of two representative manganese ores and two ferromanganese slags from the production of silicomanganese alloy in Furnace C during the MCA-EPA emission tests (July 27-August 6, 1971).

2. Samples : Sample 1 - Manganese Ore
Sample 2 - Manganese Ore
Sample 1 - Slag
Sample 2 - Slag

3. Analysis: Please analyze each sample separately for trace metals by both neutron activation analysis and emission spectroscopy (on contract, if necessary). Also analyze a representative portion for beryllium by atomic absorption.

Trace metals are defined as the following: Sb, As, Ba, Be, B, Cd, Ca, Cr, Cu, Fe, Pb, Mg, Mn, Hg, Ni, K, Se, Si, Na, Sr, S, Sn, V and Zn.

4. Results: Forward results to the author.

D. R. Patrick
D. R. Patrick
Chemical Engineer

cc: W. Basbagill
J. Dealy
S. Blacker

Results in ppm except where otherwise designated

| ple No. | Type | Date | Sample Size | Priority 1 Elements |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | Priority 2 Elements |  |  |  |  |  |  | Others |  | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | Sb As | Cd | Be | V | Mn | Ni | Cr | Sr | Zn | Cu | Pb | Se | B | F | Li | Ag | Sn | Fe | Sr | Na | K | Ca | Si | Mg | Al | P |  |
| Mn Ore #1 |  |  | ~100 g | <1 | 1-100 | <200 | 400 | Major | 200 | <100 | 100 | <200 | 200 | <50 | N | 6. | N | 200 | <1 | <50 | 2% | 300 | 4000 | 3% | 3000 | 8% | 3000 | 3% |  | OES |
| Mn Ore #2 |  |  | ~30 g | <1 | 1-100 | <200 | 200 | Major | 200 | <100 | 100 | <200 | 200 | <50 | N | 20 | N | 30 | <1 | <50 | 3% | 200 | 3000 | 2% | 1000 | 5% | 2000 | 2% |  | OES |
| Slag #1 |  |  | <30 g | <1 | 6-100 | <100 | 600 | Major | 400 | <100 | 300 | <100 | 100 | <50 | N | 60 | N | 100 | <1 | <50 | 15% | 100 | 2200 | 8% | 2000 | 3% | 3000 | 3% |  | OES |
| Slag #2 |  |  | <100 g | <1 | 8-100 | <100 | 800 | Major | 400 | <100 | 1000 | <100 | 100 | <50 | N | 60 | N | 300 | <1 | <50 | 3% | 300 | 4000 | 2% | 3000 | 8% | 3000 | 3% |  | OES |

Sample neutralized with NaOH.

Table E-11. METAL ANALYSIS OF ORE AND SLAG SAMPLES.

# IV. CHEMICAL ANALYSES OF EMISSIONS FROM A FERROCHROMESILICON FURNACE

## 1. INTRODUCTION

Particulate fumes and gaseous emissions are generated during the processing of a commercially important class of ferroalloy materials called reactive metals. The particulate portion of these emissions is collected on glass fiber filters strategically placed in the air stream of a ventilation system. Six such filters from samples collected on a FeCrSi furnace were analyzed by atomic absorption and qualitative electron beam X-ray microanalysis. Each of the six filters prior to compositing was examined microscopically.

## 2. TEST RESULTS

### 2.1 Optical Examination

The loaded filters were examined at magnifications up to 30X. Under tungsten filament illumination the separate filters appeared as follows:

| | | |
|---|---|---|
| ABD-1M | Dark gray powder with black particles-no quartz fibers from the collector pad visible. | (baghouse inlet) |
| ABD-2M | Light gray powder with very few black particles-no quartz fibers from the collector pad visible. | (baghouse inlet) |
| ABD-3M | Dark gray powder with black particles-quartz fibers from the collector pad visible. | (baghouse inlet) |
| ANE-1M | Light gray powder with black particles-quartz fibers from the collector pad visible. | (baghouse outlet) |
| ACE-1M | A few black particles among the quartz fibers. | (baghouse outlet) |
| ASE-1M | A few black particles among the quartz fibers. | (baghouse outlet) |

The optical examination revealed that:

1. Four filters had trapped a heterogeneous particulate material consisting predominantly of a gray powder and a minor amount of black particles.

2. The amount of sample collected in four cases was so small that the fibers from the filters could still be seen. In fact, in two such samples, only a small amount of the black particles could be seen against a background that was predominantly the filter material.

Two different techniques were necessary to form composite samples:

1. Simple Blending of Loose Powders

   Samples ABD-1M, ABD-2M, and ABD-3M were shaken, lightly scraped and copious amounts of loose gray material were gathered, blended, and designated as Baghouse Inlet Duct Sample ABD-M. A negligible amount of the collector filter material was included in the blended sample.

2. Dissolution in a Common Reagent

   Samples ANE-1M, ACE-1M, and ASE-1M were submerged (particulate matter and filter pads) in a common solution of sulfuric acid. A control experiment was also run on a unused filter pad to determine the contributions of the filter. The composited sample in this case was labeled Baghouse Outlet Stack Sample ABE-M.

   Small samples for electron beam X-ray microanalysis were cut from every specimen prior to formation of any composite samples.

## 2.2 Electron Beam X-Ray Microanalysis

The electron microprobe is an advanced piece of equipment which uses a small beam of electrons to produce characteristic X-ray emissions from a sample volume with a radius of ~1 micron. Curved crystal X-ray spectrometers are used to analyze the resultant characteristic X-ray spectra. An examination was made of the complex spectrum of X-rays given off by the specimen under electron beam excitation, and it was found that the entire spectrum could be identified uniquely. All portions of the X-ray spectrum in the wavelength range 1-100A covering all elements except H, He, Li, and Be were taken into account.

In these analyses, the electron beam was defocused to a diameter of ~150 microns (0.006 inch) to cover a relatively large area of the specimen and to insure that both the gray condensate and the black particles were analyzed. The electron beam impinged in vacuum on the untouched surfaces of three specimens:

1. Sample ABD-1M

   In this sample, the layer of particulate material was far too thick to allow penetration of the electron beam into the collector (filter) pad. In other words, only the condensed particulate material was analyzed in this case.

2. Sample ABD-3M

   The layer of particulate was sufficiently thin that a contribution from the collector pad may be present.

3. Sample ANE-1M

   A contribution from the collector was definitely present in this case because the fibers from the collector could be seen in the optical microscope viewing system attached to the electron microprobe.

The qualitative results are compiled in Table E-12 and provide the basis for selection of elements for quantitative analyses. Note that a total of 15 elements were found* and that the stack sample (ANE-1M contained a small but distinct amount of both sulfur and chlorine. Special mention is made of these

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* The spectral scans were conducted in a manner such that all elements except H, He, Li, Be, B, N could be detected.

Table E-12. QUALITATIVE ELECTRON BEAM X-RAY MICROANALYSES

| Specimen No. | Cr | Mn | Mg | Fe | Al | Ca | Ba | Na | K | Zn | Cl | S | Si | O | C |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ABD-3M | M | T | H | T | L | T | - | T | M | T | - | - | H | H | L |
| ABD-2M Airco Inlet Duct Sample | M | T | H | T | L | T | - | T | L | T | - | - | H | H | L |
| ANE-1M Airco Stack Sample | T | - | H | T | M | H | L | M | M | T | T | T | H | H | L |

KEY:
H = greater than 20 wt%
M = 10-20 wt%
L = 1-10 wt%
T = less than 1 wt%

elements because they were not included in the quantitative analyses which will be described in the next paragraph. Note also that oxygen was detected at about the 50%, thereby suggesting that the particulate material was a mixture of oxides.

## 2.3 Atomic Absorption Analyses

Atomic Absorption (A.A.) means that a cloud of atoms in the un-ionized and unexcited state is capable of absorbing radiation at wavelengths that are specific in nature and characteristic of the element in consideration. The atomic absorption spectrophotometer used in these analyses consists of a series of lamps which emit the spectra of the elements determined, a gas burner to produce an atomic vapor of the sample, a monochromator to isolate the wavelengths of interest, a detector to monitor the change of absorption due to the specimen, and a readout meter to visualize this change in absorption.

As stated previously, the two sets of samples were composited two different ways for the atomic absorption analyses. The detailed procedures for the physically blended powders are as follows:

1. The particulate material from three specimens was either shaken loose or scraped from the filter pads with a wood tongue depresser and blended in a polyethylene container.
2. Duplicate portions of the blended powder were digested in hot $HCl\text{-}HNO_3$.* After cooling, the suspension was filtered.
3. The filtrate (soluble portion) was analyzed for the elements of interest by atomic absorption. The precipitate (non-soluble portion) was analyzed by "large beam" electron microprobe analysis and flame photometry and found to be free of sodium or potassium. This action was done because potassium acid sulfate ($KHSO_4$) was used in the next step.
4. The precipitate was blended with a known quantity of $KHSO_4$ and ignited in a 850°C muffle furnace to form a fused mass which subsequently was dissolved in HCl. Solution was not complete, and a filtration step was needed to separate the solution from a precipitate.
5. The solution was analyzed for the elements of interest by atomic absorption, and the results from this step were added to those from Step 3 to yield the total percentage of each element in the particulate sample.

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* The hot solution used was 8 ml concentrated HCl, 32 ml concentrated $HNO_3$ and 40 ml distilled water.

6. The precipitate from Step 4 was checked for $SiO_2$ by a gas evolution technique.* This technique selectively decomposes and volatilizes $SiO_2$ through reaction with hot $H_2SO_4$, $HNO_3$ and HF in a platinum crucible. The portion of the sample that still remained after all these steps was labeled an insoluble residue in Table E-13.

A different procedure was needed for those samples in which the quantity of condensable particulate was insufficient for a physical separation. In this case the following procedure was used:

1. Three entire collector pads, with material in and on them, were digested in a common hot $H_2SO_4$ solution. An unused collector pad was submerged in a second identical solution.
2. The steps described previously were followed for both the unknown and the unused sample. The results for the latter were corrected to account for the fact that three used pads were used with the unknown samples but only one unused pad was employed as a blank.
3. The concentrations of elements in the condensable particulate material was obtained by subtracting the results for the "blank" from the total.

The results of the atomic absorption analyses are compiled in Table E-13. The following are observations.

1. Both samples are predominantly silicon dioxide, $SiO_2$. This conclusion is directly seen in the results for the Inlet Duct Sample where 76.4% of the material is $SiO_2$. The concentrations of the remaining elements are all low in comparison, and magnesium is the highest at an average 5.44% level. The sum of all the percentage values is 100%, and this indicates excellent closure (mass balance). The 100% value is achieved when all the metal percent values are converted to their equivalent oxide percent values.**

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* N. H. Furman, Editor, Standard Methods of Chemical Analysis, 6th Edition, Volume 1, D. Van Nostrand Company, Princeton, N. J., p. 950.

** Equivalent oxide percentages are obtained by multiplying the weight percent metal in Table 2 by the ratio Mo/Mm where Mo is the molecular weight of the metal oxide and Mm is that of the metal.

Table E-13. ELEMENTAL ANALYSIS OF PARTICULATE MATTER COLLECTED AT OUTLET AND INLET OF A BAGHOUSE SERVING A FERROCHROMESILICON FURNACE (atomic absorption)

| Sample | Element wt% | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Na | K | Mn | Fe | Zn | Cr | Ca | Mg | Al | Ba | Ti | $SiO_2$ | Insoluble Residue[b] |
| ABE-M Stack Sample | 12.7 | 0.9 | 0.1 | 1.0 | 0.6 | <.4 | 4.0 | 0.6 | 8.0 | <4. | <8. | a | |
| ABD-M Inlet Duct Sample | 0.23<br>0.22 | 0.25<br>0.25 | 0.054<br>0.050 | 0.10<br>0.08 | 0.32<br>0.37 | 0.46<br>0.42 | 0.59<br>0.27 | 5.28<br>5.59 | 0.38<br>0.35 | <.4 | <.8 | 76.8<br>76.0 | 11.5<br>13.2 |

[a] No $SiO_2$ quantitative results were determined for this sample which was a composite of three filters and their condensable particulate samples. The sample was known in advance to be predominantly $SiO_2$.

[b] The residue that seemed to defy attempts at dissolution was analyzed on the electron beam X-ray microanalyzer and found to be primarily (~50%) platinum (from the platinum crucibles used) with lesser amounts of aluminum, sodium, and fluorine. The latter group of elements probably are evidence of incomplete digestion in the hot acid steps conducted early in the analysis-separation scheme.

2. The Stack Sample, in comparison with the Inlet Duct Sample, contains relatively more of every metal cation except magnesium. The absolute amount of the Stack Sample was far less and this had an impact on the sensitivity values. Thus the lower limits for barium and titanium are 4% and 8% in the Stack Sample (rather than 0.4 and 0.8%) because the total sample mass was limited to ~11 milligrams.

3. It must be emphasized that the values have been corrected to account for the contributions from the filter pads. In other words, the 12.7% Na value is for the particulate matter collected on a filter and not for the filter pad.

Metals analysis was also made on two chrome ore samples using the optical emission spectrography method. These are shown in Table E-14.

## Table E-14. OPTICAL EMISSION SPECTROGRAPHY[a]

| | Hg | Be | Cd | As | V | Mn | Ni | Sb | Cr | Zn | Cu | Pb | Se | B | Li | Ag | Sn | Fe | Sr | Na | K | Ca | Si | Mg | Al | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B-58 Chrome Ore Turk 2331 | <1. | <2. | <100. | <200. | 500. | 1000. | 1000. | <100. | 30.% | <200. | <20. | <100. | | <20. | <10. | <2. | <100. | 5.% | <100. | 100. | <500. | 3000. | 4.% | 10.% | 7.% | -- |
| B-59 Chrome Ore Turk 2238 | <1. | <2. | <100. | <200. | 500. | 1000. | 1000. | <100. | 30.% | <200. | <20. | <100. | -- | <20. | <10. | <2. | <100. | 5.% | <100. | 100. | <500. | 4000. | 4.% | 10.% | 7.% | - |

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[a] Results in ppm of as-received sample except where otherwise designated.

FURNACE D

**ENVIRONMENTAL PROTECTION AGENCY**
Office of Air Programs
Research Triangle Park, North Carolina 27711

*Reply to Attn of:* ATD

*Date:* May 5, 1972

*Subject:* $SO_4^=$ Analysis of Particulate Samples from Furnace D

*To:* Winton Kelly, Chemical Engineer, Petroleum & Chemical Section

Two sample fractions (organic extract and impinger water residue) were selected for sulfate analysis from each of the two sample tests, ANE-1 and ABD-2. These samples were first analyzed by the Barium Perchlorate titration method, which proved to be too in-sensitive. Re-analysis by the more sensitive Sulfaver-Turbidimetric procedure gave the following results:

| Test No. | Beaker No. | (mg) Original Sample Weight | Mg $SO_4^=$ Sample | Weight Percent $SO_4^=$ | Sample Fraction | |
|---|---|---|---|---|---|---|
| ANE-1 | 31 | 8.1 | <0.25 | < 3 | Organic Extract | BAGHOUSE OUTLET |
| ANE-1 | 43 | 18.8 | 6.75 | 33 | Impinger Water Residue | |
| ABD-2 | 35 | 35.8 | <0.25 | < 1 | Organic Extract | BAGHOUSE INLET |
| ABD-2 | 47 | 42.4 | 5.55 | 13 | Impinger Water Residue | |

An acid-base titration of beakers 35 and 47, using 0.1009 N NaOH, used less than one drop per sample, indicating both samples were very near neutrality. Beakers 31 and 43 were not subjected to an acid-base titration due to a lack of sample volume after the $SO_4^=$ analysis.

Remnants of test ABD-2 (beakers 35 and 47) have been sealed to prevent contamination and are located at the IRL Building sample storage area. Any questions regarding these samples or the data can be directed to me (X277) or found in the laboratory notebook located in Room 26, at the IRL Building.

Frank Wilshire
Frank Wilshire
Chemist
Petroleum & Chemical Section
Emission Testing Branch, ATD

cc: Mr. W. Grimley
Mr. H. Crist

FURNACE D

ENVIRONMENTAL PROTECTION AGENCY
Research Triangle Park, North Carolina 27711

*Reply to Attn of:*

*Date:* 5/3/72

*Subject:* Ferro-Alloy Samples

*To:* Winton Kelly, ETB
Petroleum & Chemical Section

The results of analyses on the above samples collected from Furnace D are attached.

Your samples are identified as follows:

| Battelle No. | EPA Test No. | Sample Fraction | |
|---|---|---|---|
| B-272 | ABD-2 | Solvent extraction of impinger water | BAGHOUSE INLET |
| B-273 | ABD-2 | Impinger water residue | |
| B-274 | ACE-1 | Solvent extraction of impinger water | BAGHOUSE OUTLET |
| B-275 | ABD-1 | Impinger water residue | BAGHOUSE INLET |
| B-276 | ACE-1 | Impinger water residue | BAGHOUSE OUTLET |
| B-277 | ABD-1 | Solvent extraction of impinger water | BAGHOUSE INLET |
| B-278 | ANE-2 | Impinger water residue | BAGHOUSE OUTLET |
| B-279 | ANE-2 | Solvent extraction of impinger water | |

Howard Crist
Howard L. Crist
Chief, Source Sample Analysis Section
SSFAB, DAS

Attachment

cc: W. Grimley

## Table E-15. METAL AND OTHER ANALYSES OF COLLECTED PARTICULATES FROM FURNACE D

(μg/sample)

Determinations requested: anions, water insolubles, organic material, trace metals, pH

Type analysis: VAS, OES

| | Sample designation | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | B272 | B273 | B274 | B275 | B276 | B277 | B278 | B279 |
| Be | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Cd | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| As | 10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| V | 3 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Mn | 100 | 200 | <1 | 200 | 10 | 80 | 10 | <1 |
| Ni | 30 | 30 | <1 | 30 | 2 | 5 | 2 | <1 |
| Sb | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| Cr | 1000 | 1000 | <1 | 600 | 3 | 600 | 10 | <1 |
| Zn | 150 | 300 | <10 | 50 | 10 | 30 | 20 | <10 |
| Cu | 10 | 10 | <1 | 7 | 5 | 5 | 7 | <1 |
| Pb | 200 | 300 | <5 | 300 | 5 | 30 | 5 | <5 |
| B | 3 | 3 | 1 | 3 | 1 | 5 | 1 | <1 |
| Li | <5 | <5 | <5 | 5 | <5 | <5 | <5 | <5 |
| Ag | 3 | 1 | <0.1 | 0.1 | <0.1 | 1 | 0.1 | <0.1 |
| Sn | 30 | 10 | <5 | 10 | 5 | 20 | 5 | <5 |
| Fe | 700 | 300 | 5 | 300 | 20 | 300 | 50 | 1 |
| Sr | <5 | <5 | <5 | <5 | <5 | <5 | <5 | <5 |
| Na | 1000 | 2000 | <10 | 800 | 100 | 300 | 100 | <10 |
| K | 2000 | 2000 | <10 | 1000 | 30 | 800 | 30 | <10 |
| Ca | 150 | 700 | 20 | 400 | 100 | 200 | 200 | <1 |
| Si | 100,000 | 50,000 | 200 | 40,000 | 200 | 120,000 | 200 | 5 |

## Table E-14 (continued). METAL AND OTHER ANALYSES OF COLLECTED PARTICULATES FROM FURNACE D

(μg/sample)

Determinations requested: anions, water insolubles, organic material, trace metals, pH

Type analyses: VAS, OES

| | Sample designation | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | B272 | B273 | B274 | B275 | B276 | B277 | B278 | B279 |
| Mg | 5000 | 15,000 | 10 | 12,000 | 5 | 4000 | 30 | <1 |
| Bi | 5 | 2 | <1 | <1 | <1 | <1 | <1 | <1 |
| Co | 1 | 1 | <1 | 3 | <1 | 5 | 10 | <1 |
| Ge | <3 | <3 | <3 | <3 | <3 | <3 | <3 | <3 |
| Mo | 3 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Ti | 20 | 3 | <1 | 1 | 3 | 5 | 5 | 1 |
| Zr | 3 | <1 | <1 | <1 | <1 | <1 | <1 | <1 |
| Ba | 50 | 20 | <1 | 10 | 2 | 50 | 2 | <1 |
| Al | 2000 | 1000 | 10 | 1200 | 40 | 1200 | 60 | <3 |
| $SO_4$ | < 500 | 24,000 | < 500 | 22,000 | 6800 | <500 | 10,000 | <500 |
| Cl | 30 | 1000 | <20 | 60 | <20 | <20 | <20 | 20 |
| $NH_4$ | <30 | 120 | 70 | 700 | 1000 | <30 | 750 | <30 |
| $NO_3$ | < 100 | 200 | 100 | 100 | <100 | <100 | 100 | <100 |
| Water insoluble | 223,000 | 191,700 | 3500 | 41,300 | 2200 | 121,500 | None | None |
| Organic | 16,500 | 2000 | 1400 | 2000 | 1000 | 4000 | 1000 | 400 |
| pH | 6.2 | 6.1 | 5.4 | 4.5 | 3.2 | 6.3 | 2.7 | 5.3 |

# V. CHEMICAL ANALYSES OF EMISSIONS
# FROM
# AN HC FERROCHROME FURNACE

Particulate fumes and gaseous emissions are generated during processing of an important class of ferroalloy materials called reactive metals. The particulate portion of the emissions is collected on glass fiber filters strategically placed in the air stream of a ventilation system. Two such filters of a sample collected at the outlet of a furnace producing HC ferrochrome were analyzed by the combined techniques of a electron beam X-ray analysis and atomic absorption analysis, and the results are detailed in the following paragraphs.

## 2. TEST RESULTS

### 2.1 Optical Examination and Compositing

The two samples were gray and were labeled WCD and ECD. Small portions were cut for electron microprobe analyses. The remainder was shaken and a copious amount of loose powder was gathered, blended, and designated Precipitator Inlet Duct CD-M.

### 2.2 Electron Beam X-Ray Microanalysis and Atomic Absorption

The electron microprobe is an advanced piece of equipment which uses a small beam of electrons to produce characteristic X-ray emissions from a sample volume with a radius of ~1 micron. Curved crystal X-ray spectrometers are used to analyze the resultant characteristic X-ray spectra. In these analyses, the electron beam was defocused to a diameter of 150 microns (0.006 inch) to cover a larger segment of the sample. The electron beam impinged in vacuum upon the untouched surfaces of small pie-shaped pieces of sample-covered filter pads. An examination was made of the complex spectrum of X-rays given off by the specimen under electron beam excitation, and it was found that the entire spectrum could be identified uniquely. All portions of the X-ray spectrum in the wavelength range 1-100A covering all elements except H, He, Li, and Be were taken into account.

Atomic Absorption (A.A.) means that a cloud of atoms in the un-ionized and unexcited state is capable of absorbing radiation at wavelengths that are specific in nature and characteristic of the element in consideration. The atomic absorption spectrophotometer used in these analyses consists of a series of lamps which emit the spectra of the elements determined, a gas burner to produce an atomic vapor of the sample, a monochromator to isolate the wavelengths of interest, a detector to monitor the change of absorption due to the specimen, and a readout meter to visualize this change in absorption.

The qualitative electron microprobe results are in Table E-16, along with the quantitative atomic absorption results. The latter were generated on the composited samples mechanically separated from the filter (collector) pads by shaking and lightly scraping the filters. A negligible amount of collector filter material was included in the blended sample, and therefore no unused filter pad was needed.

The sum of the percent values, after conversion to equivalent oxide values, is 84% and indicates adequate closure in the sense that all the major constituents have been taken into account. The remaining 16% could well be accounted for by the presence of chlorine, carbon, and titanium.

The major conclusion is that the sample is a mixture of oxides: $SiO_2$, $Cr_2O_3$, MgO, and $Al_2O_3$.

X-ray diffraction analyses were not executed, and hence it is not known if the oxide mixture is amorphous (non-crystalline), crystalline (spinel structure), or partially amorphous-partially crystalline.

A sample was obtained from the precipitator and analyzed for metals by the Optical Emission Spectrography (OES) method. This sample does not necessarily represent true emissions from the furnace since some particulates are removed by the conditioning tower preceding the precipitator.

Table E-16. QUALITATIVE ELECTRON BEAM X-RAY MICROANALYSIS AND ATOMIC ABSORPTION RESULTS FROM SAMPLE COLLECTED AT PRECIPITATOR INLET DUCT (FURNACE E)

| Sample CD-M | Cr | Mn | Mg | Fe | Al | Ca | Ba | Na | K | Zn | Cl | S | $SiO_2$ | O | C | Ti |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electron Beam | H | L | H | M | M | L | - | M | M | L | H | L | H | H | L | T |
| Atomic Absorption | 14.0 | 0.18 | 8.90 | 3.66 | 6.33 | 0.27 | 0.11 | 4.22 | 5.95 | 0.93 | a | a | 15.0 | a | a | a |

H = high >10%

M = medium 1-10%

L = low 0.1-1%

T = trace ~<0.1%

[a] Quantitative atomic absorption analyses were not performed.

## SOURCE SAMPLE REQUEST & REPORT

(MUST BE FILLED OUT FOR EACH TEST RUN)

SAMPLING DATE 71 | 9 | 23 (YR | MO | DAY)

FIRST IDENT. NO. USED B-41

LAST IDENT. NO USED —

TEST NO ________

RUN NO ________

INDUSTRY FURNACE E (USE TABLE A)

COMPANY ________

ADDRESS ________

SAMPLING METHOD REPRESENTATIVE GRAB SAMPLE OBTAINED FROM PRECIPITATOR COLLECTION HOPPER

UNIT PROCESS OPERATION HC FERROCHROME FURNACE

AIR POLLUTION CONTROL ELECTROSTATIC PRECIPITATOR

FUEL USED NONE

☐ INLET ☐ OUTLET

GAS VOLUME SAMPLED (METER VOL IN FT$^3$) —

| IDENT NO | DESCRIPTION OF SAMPLE OR SAMPLE FRACTION | SAMPLE | | ANALYSIS REQUESTED - GENERAL COMMENTS (APPROX CONCENTRATIONS - POSSIBLE INTERFERENCES ETC) (INDICATE SPECIFIC ANALYSIS ON BACKSIDE) |
|---|---|---|---|---|
| | | WT (SOLID) MG | VOL (LIQUID) ML | |
| B-41 | PRECIPITATOR COLLECTED DUST | - | | METALS ANALYSIS |
| | | | | |
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| | | | | |

COMMENTS: ________

SAMPLING CONTRACTOR ________ (IF APPLICABLE)

PROJECT OFFICER ________

REQUEST REVIEWED BY ________

DATE OF REQUEST ________

DATE ANALYSIS REQUESTED ________

DATE OF REQUEST ________ (TO BE FILLED IN BY SSFAB)

EPA(DUR)245

REPORT OF ANALYSIS
TRACE ELEMENTS
ppm - for solid samples
ug/ml - for liquid samples

| Ident No. | Hg | Be | Cd | As | V | Mn | Ni | Sb | Cr | Zn | Cu | Pb | Se | B | F | Li | Ag | Sn | Fe | Sr | Na | K | Ca | Si | Mg | Ba | AL | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B-41 | <1 | <2 | <100 | <200 | 60 | 2000 | 100 | <100 | 4% | 5000 | 600 | 1000 | N | 40 | N | 1000 | 10 | 300 | 1% | <100 | 15% | 10% | 3000 | 8% | 15% | | 5% | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Analysis Method: 1-NAA, 2-SSMS, [✓ 3-OES] 4-AA, 5-ASV, 6-XRF, and 7-other

Comments:

Other Analysis - Use Table B to fill analysis requested (above each column)

Mark (x) for specific analysis requested

| Ident No. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Analyst | | | | | | | | | | |
| Method | | | | | | | | | | |

Comments:

Table E-17. ANALYSIS OF PARTICULATES COLLECTED IN A PRECIPITATOR

# VI. CHEMICAL ANALYSIS OF EMISSIONS
# FROM
# A SILICON METAL FURNACE

## I. INTRODUCTION

Particulate samples were collected using an EPA sampling train at the inlet and outlet of a baghouse serving a silicon metal furnace. Chemical analyses were made of the particulates collected in each section of the sampling train. For the use of Table E-18, sample numbers are identified as follows:

| Description of sample or sample fraction | Sample No. | |
|---|---|---|
| | Baghouse inlet | Baghouse outlet |
| Probe wash residue | 165,188 | 137,152 |
| Glass fiber filter | (166,167,168,169),189 | 138,153 |
| Impinger aceton wash residue | 170,190 | 139,154 |
| Impinger water residue | 171,191 | 140,155 |
| Chloroform-ether extraction residue | 172,192 | 141 |

Sample numbers 137 through 141 were for a test run at the baghouse outlet. Samples 152 through 155 were also for a test run at the baghouse outlet. Samples 165 through 172 were for a test run at the baghouse inlet. Samples 166, 167, 168 and 169 were combined into one sample. Sample numbers 188 through 192 were analyzed representing a test at the baghouse inlet.

The samples were water leached for the anion and $NH_4^+$ analysis, and they were acetone leached for the total organic analysis; portions of these leaches were combined with a portion from an additional acid leach-scrubbing step to obtain a sample for optical emission spectrograph (OES). A portion of each filter was water and acetone leached for the organics, anions, and $NH_4^+$; a separate portion of each filter was acid extracted for the OES sample.

The analysis of the filter and residue samples are shown in Table E-18. Results are reported in micrograms per entire filter or residue. The weights of the samples analyzed are:

| Sample No. | Wt. in Mg |
|---|---|
| 137 | 153.6 |
| 138 | 10.4 |
| 139 | 23.1 |
| 140 | 21.2 |
| 141 | 3.4 |
| 152 | 13.1 |
| 153 | 16.8 |
| 154 | 27.5 |
| 155 | 25.0 |
| 165 | 486.3 |
| 166 | 1017.4 |
| 167 | 701.8 |
| 168 | 923.0 |
| 169 | 1404.4 |
| 170 | 30.7 |
| 171 | 59.6 |
| 172 | 68.6 |
| 188 | 9.5 |
| 189 | 18.8 |
| 190 | 20.6 |
| 191 | 23.2 |
| 192 | 1.0 |

## Table E-18. ANALYSIS OF FILTERS AND RESIDUES

(Results in micrograms per entire filter or residue)

Contract No. 68-02-0447

Determinations Requested - Priority I and II elements; Anions

Types of Analyses - Optical Emission Spectrographic (OES)
Visual Absorption Spectrophotometric (VAS)

| Element | Identification No.[a] -137 | -138 | -139 | -140 | -141 | -152 | -153 | -154 | -155 |
|---|---|---|---|---|---|---|---|---|---|
| Be | <0.3 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Cd | <15. | <2. | <5. | <5. | <5. | <5. | <2. | <5. | <5. |
| As | <30 | <20. | <10. | <10. | <10. | <10. | <20. | <10. | <10. |
| V | <7. | <6. | <1. | <1. | <1. | <1 | <6. | <1. | <1. |
| Mn | 800. | 30. | 4. | 3. | <1. | 10. | 15. | 2. | 3. |
| Ni | 40. | <5. | 1. | <1. | <1. | 10. | 20. | <1. | <1. |
| Sb | <15. | <20. | <5. | <5. | <5. | <5. | <20. | <5. | <5. |
| Cr | 500. | 6. | 4. | 1. | <1. | 12. | 30. | 4. | 3. |
| Zn | 600. | 20. | 50. | 40. | <10. | 50. | 40. | 50. | <10. |
| Cu | 12. | T<2. | 1. | 2. | 0.2 | 3. | T<2. | 0.5 | 0.7 |
| Pb | 50. | 10. | <3. | 10. | <3. | 15. | <10. | 10. | <3. |
| Se | - | - | - | - | - | - | - | - | - |
| B | 12. | 300. | 15. | 2. | 1. | 1. | 500. | 10. | <1. |
| F | - | - | - | - | - | - | - | - | - |
| Li | <80. | - | <30. | <30. | <30. | <30. | - | <30. | <30. |
| Ag | <0.3 | - | <0.1 | 0.5 | 0.1 | <0.1 | - | <0.1 | <0.1 |
| Sn | 12. | <5. | <3. | <3. | <3. | 5. | 10. | 5. | <3. |
| Fe | 2,000. | 100. | 13. | 15. | 6. | 70. | 60. | 20. | 15. |
| Sr | <8. | 40. | <3. | <3. | <3. | <3. | 30. | <3. | <3. |
| Na | 100. | 300. | 30. | <10. | <10. | 10. | 300. | 10. | 10. |
| K | 700. | 1,700. | 20. | <10. | <10. | 10. | 1,700. | <10. | 10. |
| Ca | 800. | 600. | 200. | 400. | 25. | 15. | 600. | 40. | 20. |
| Si | 40,000. | - | 2,000. | 250. | 200. | 500. | - | 600. | 200. |
| Mg | 300. | 300. | 15. | 25. | 12. | 10. | 300. | 3. | 12. |
| Bi | <3. | <6. | <1. | <1. | <1. | <1. | <6. | <1. | <1. |
| Co | <3. | <6. | <1. | <1. | <1. | <1. | <6. | <1. | <1. |
| Ge | <10. | - | <3. | <3. | <3. | <3. | - | <3. | <3. |
| Mo | <3. | <2. | <1. | <1. | <1. | <1. | <2. | <1. | <1. |
| Ti | 70. | 2. | 1. | 2. | <1. | 1. | T<2. | <1. | <1. |
| Sn | - | - | - | - | - | - | - | - | - |
| Ta | <30. | - | <10. | <10. | <10. | <10. | - | <10. | <10. |
| Th | <30. | - | <10. | <10. | <10. | <10. | - | <10. | <10. |
| Zr | 400. | - | <1. | <1. | <1. | <1. | - | <1. | <1. |
| Ba | 400. | - | 8. | 3. | 3. | 5. | - | 10. | 5. |
| Al | 3,000. | 1,000. | 40. | 15. | 3. | 10. | 1,000. | 15. | 13. |
| $SO_4^{=}$ | 1,000. | <500. | <500. | 16,200. | <500. | <500. | <500. | <500. | 19,800. |
| Cl- | 360. | 690. | 220. | <40. | <40. | 50. | 1,100. | 60. | <40. |
| $NO_3^-$ | <100. | <400. | 200. | 1,400. | <100. | 500. | 400. | 600. | 900. |
| $NH_4^+$ | 80. | <30. | 30. | 810. | <30. | <30. | <30. | 50. | 530. |
| Organic[b] | 5,600. | 4,000. | 11,800. | - | - | 5,400. | 5,200. | 15,800 | - |
| $H_2O$ Insol. | 141,200. | 176,000. | 12,500. | - | - | 2,500. | 193,200. | 14,800. | - |
| pH | - | - | - | 2.5 | 5.2 | - | - | - | 2.4 |

Table E-18. (Continued)

| Element | -165 | -166,-167,-168,-169 | -170 | -171 | -172 | -188 | -189 | -190 | -191 | -192 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Identification No.[a] | | | | | | | | | |
| Be | <1. | <5. | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Cd | <50. | <200. | <5. | <5. | <5. | <5. | <2. | <5. | <5. | <5. |
| As | <90. | <500. | <10. | <10. | <10. | <10. | <20. | <10. | <10. | <10. |
| V | <30. | <50. | <1. | <1. | <1. | <1. | <5. | <1. | <1. | <1. |
| Mn | 600. | 500. | 5. | 30. | 6. | 15. | 30. | 4. | 10. | <1. |
| Ni | 600. | <25. | 2. | 20. | 5. | 15. | <5. | <1. | <1. | <1. |
| Sb | <50. | <250. | <5. | <5. | <5. | <5. | <20. | <5. | <5. | <5. |
| Cr | 250. | <50. | 1. | 4. | 5. | 15. | 6. | 4. | <1. | <1. |
| Zn | 300. | <500. | 30. | 20. | <10. | 60. | 20. | 100. | 30. | <10. |
| Cu | 170. | 50. | 1. | 1. | 2. | 5. | T<2. | 2. | 1. | 0.5 |
| Pb | 90. | 150. | <3. | 12. | 12. | 10. | <10. | 25. | 5. | <3. |
| Se | - | - | - | - | - | - | - | - | - | - |
| B | 30. | 90. | 1. | <1. | 3. | 1. | 500. | 20. | <1. | 1. |
| F | - | - | - | - | - | - | - | - | - | - |
| Li | <300. | <1,300. | <30. | <30. | <30. | <30. | - | <30. | <30. | <30. |
| Ag | 1. | <5. | 1. | 0.1 | <0.1 | 0.3 | - | <0.1 | 0.3 | <0.1 |
| Sn | 150. | 250. | 15. | 15. | 15. | <3. | <6. | <3. | <3. | <3. |
| Fe | 1,400. | 500. | 8. | 40. | 20. | 70. | 100. | 30. | 40. | 10. |
| Sr | <30. | <150. | <5. | <3. | <3. | <3. | 30. | <3. | <3. | <3. |
| Na | 100. | <500. | 10. | 20. | <10. | 30. | 300. | 40. | 50. | <10. |
| K | 700. | 5,000. | 10. | 40. | 60. | <10. | 1,700. | <1. | 20. | <10. |
| Ca | 900. | 100. | 20. | 1,200. | 100. | 15. | 600. | 15. | 200. | 10. |
| Si | 140,000. | 700,000. | 3,000. | 1,200. | 14,000. | 700. | - | 2,700. | 150. | 150. |
| Mg | 300. | 1,000. | 10. | 40. | 40. | 25. | 300. | 15. | 20. | 2. |
| Bi | <10. | <50. | <1. | <1. | <1. | <1. | <6. | <1. | <1. | <1. |
| Co | <10. | <50. | 1. | 20. | <1. | <1. | <6. | <1. | <1. | <1. |
| Ge | <30. | <150. | <3. | <3. | <3. | <3. | - | <3. | <3. | <3. |
| Mo | 50. | <50. | <1. | <1. | <1. | <1. | <2. | <1. | <1. | <1. |
| Ti | 90. | <50. | 1. | <1. | 3. | 1. | <2. | 1. | <1. | <1. |
| Sm | - | - | - | - | - | - | - | - | - | - |
| Te | <90. | <500. | <10. | <10. | <10. | <10. | - | <10. | <10. | <10. |
| Th | <90. | <500. | <10. | <10. | <10. | <10. | - | <10. | <10. | <10. |
| Zr | <10. | <50. | <1. | <1. | <1. | <1. | - | <1. | <1. | <1. |
| Ba | 25. | 70. | <1. | 3. | 1. | 10. | - | 10. | 1. | 5. |
| Al | 900. | 5,000. | 20. | 40. | 50. | 40. | 1,000. | 25. | 50. | 3. |
| $SO_4^=$ | <500. | <500. | <500. | 36,000. | <500. | <500. | <500. | <500. | 17,900. | <500. |
| $Cl^-$ | 1,500. | <1,000. | 110. | <40. | 40. | <50. | 800. | 140. | <40. | 40. |
| $NO_3^-$ | 400. | 400. | <100. | 800. | <100. | 500. | 500. | 300. | 1,100. | <100. |
| $NH_4^+$ | 200. | 100. | 130. | 490. | <30. | <30. | <30. | 90. | 550. | <30. |
| Organic[b] | 22,000. | 17,000. | 5,200. | - | - | 3,000. | 2,400. | 13,800. | - | - |
| $H_2O$ Insol. | 480,000. | 2,210,000. | 19,200 | - | -- | <1,000. | 197,200. | 10,100. | - | - |
| pH | - | - | - | 2.2 | 4.1 | - | - | - | 2.4 | 3.8 |

[a] Identification Number is 72-001-XXX.

[b] Acetone soluble organic material.

- = Not sought.

# CHEMICAL ANALYSIS OF EMISSIONS
# FROM
# SILICOMANGANESE FURNACE

## I. INTRODUCTION

Inlet and outlet scrubber samples collected by the use of the EPA particulate sampler were chemically analyzed using optical emission (OES) and visual absorption spectrophotometry (VAS). For the purpose of identifying the results shown in Table E-19, the following information is given:

| Sample No. | Description of samples or sample fraction analyzed |
|---|---|
| B-338 | Probe wash residue |
| B-339 | Glass fiber filter |
| B-340 | Glass fiber filter |
| B-341 | Glass fiber filter |
| B-342 | Impinger water residue |
| B-343 | Chloroform-ether extract |
| B-344 | Impinger acetone wash residue |
| B-345 | Probe wash residue |
| B-346 | Glass fiber filter |
| B-347 | Impinger water residue |
| B-348 | Chloroform-ether extract |
| B-349 | Impinger acetone wash residue |
| B-350 | Blank glass fiber filter |
| B-351 | Blank glass fiber filter |

Sample numbers from B-338 through B-344 represented portions of one test collected at the scrubber inlet. Samples from B-345 through B-351 represents portions of one test collected at the scrubber inlet.

Filter samples B-339, B-340, B-341 and B-346 had in the packages mailed to the contractor doing the analysis some loose material that had been shaken from the filters during shipping and handling. The loose material and the filters themselves were analyzed separately for convenience, but the data were combined into a single reported value for each determination.

The appropriate blank corrections were made in the data for the filter samples, as indicated in the footnotes to Table E-18. The very large blank values for certain elements led to high "less than" values for the filters with sample even though these elements are almost certainly present in the sample, as indicated by their presence in the loose material. However, some particles of the glass fiber filters may also be in the loose material, and so it is very difficult to determine the true net amount of these elements in the actual sample.

Material balance for these samples is not good, but this may be due to the silicon content which cannot be determined for reasons given above.

Table E-89 ANALYSIS OF FILTER AND RESIDUE SAMPLES Furnace 6

(Expressed as milligrams per entire sample)

Contract No. 68-02-0447

Determinations Requested - Priority I and II Elements; Anions

Types of Analysis - Optical Emission Spectrography (OES); Visual Absorption Spectrophotometry (VAS

| Element | Sample Designation | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B-338<sup></sup>(a) | B-339(b) | B-340(b) | B-361(b) | B-342<br>H2O | B-343<br>[illegible] | B-344<br>[illegible] | B-345<br>[illegible] | B-346(b)<br>[illegible] | B-347<br>H2O | B-348<br>[illegible] | B-349<br>[illegible] | B-350(c) | B-351(c |
| Be | <0.004 | <0.008 | <0.005 | <0.007 | <0.0001 | <0.0001 | <0.0001 | <0.001 | <0.002 | <0.0001 | <0.0001 | <0.0001 | <0.001 | <0.003 |
| Cd | <0.2 | <0.2 | <0.05 | <0.2 | <0.005 | <0.005 | <0.005 | <0.005 | <0.03 | <0.005 | <0.005 | <0.005 | <0.007 | <0.02 |
| As | <0.4 | <0.5 | <0.1 | <0.4 | <0.01 | <0.01 | <0.01 | <0.01 | <0.06 | <0.01 | <0.01 | <0.01 | <0.02 | <0.06 |
| V | 0.09 | <0.05 | <0.015 | <0.04 | <0.001 | <0.001 | <0.001 | <0.002 | <0.006 | <0.001 | <0.001 | <0.001 | <0.002 | <0.003 |
| Mn | 600. | 700. | 190. | 680. | 1. | 0.003 | 0.02 | 0.01 | 40. | 0.05 | 0.001 | 0.02 | 0.007 | 0.015 |
| Ni | 0.4 | 0.12 | 0.02 | 0.1 | 0.01 | <0.001 | <0.001 | <0.001 | 0.012 | <0.001 | <0.001 | <0.001 | <0.002 | <0.003 |
| Sb | <0.2 | <0.2 | <0.07 | <0.2 | <0.005 | <0.005 | <0.005 | <0.005 | <0.04 | <0.005 | <0.005 | <0.005 | <0.004 | <0.015 |
| Cr | 2. | 0.8 | 0.2 | 1. | 0.04 | 0.001 | 0.003 | 0.003 | 0.12 | <0.001 | <0.001 | <0.001 | 0.004 | .015 |
| Zn | 2. | 4. | 0.8 | 4. | 0.03 | <0.01 | <0.01 | <0.01 | 0.4 | <0.01 | <0.01 | <0.01 | 0.06 | .2 |
| Cu | 1. | 1. | 0.2 | 0.04 | 0.01 | <0.001 | 0.001 | <0.001 | 0.12 | 0.001 | <0.001 | <0.001 | 0.004 | <0.007 |
| Pb | 0.1 | 0.8 | 0.6 | 0.9 | 0.02 | <0.005 | <0.005 | <0.005 | 0.14 | <0.005 | <0.005 | <0.005 | <0.004 | <0.01 |
| B | 0.07 | <2. | <2. | <2. | 0.003 | <0.001 | <0.001 | <0.001 | 0.07 | 0.003 | <0.001 | <0.001 | 2. | 6. |
| Li | 0.1 | 0.11 | 0.02 | 0.09 | <0.03 | <0.03 | <0.03 | <0.03 | 0.015 | <0.03 | <0.03 | <0.03 | <0.002 | <0.007 |
| Ag | 0.1 | 0.04 | 0.006 | 0.07 | 0.0003 | 0.0001 | <0.0001 | <0.0001 | 0.004 | <0.0001 | <0.0001 | <0.0001 | <0.001 | <0.004 |
| Sn | <0.2 | <0.2 | <0.1 | <0.2 | 0.01 | 0.005 | 0.01 | <0.005 | <0.02 | <0.005 | <0.005 | <0.005 | <0.004 | <0.015 |
| Fe | 40. | 2. | <1. | 5. | 0.15 | 0.003 | 0.005 | 0.005 | 0.4 | 0.001 | 0.003 | 0.005 | 0.1 | 0.3 |
| Sr | <0.2 | <0.2 | <0.08 | <0.2 | <0.005 | <0.005 | <0.005 | <0.005 | 0.02 | <0.005 | <0.005 | <0.005 | 0.02 | 0.06 |
| Na | 20. | <5. | <20. | <5. | 0.05 | <0.01 | <0.01 | <0.01 | <9. | <0.01 | <0.01 | <0.01 | 20. | 60. |
| K | 60. | 65. | 20. | 75. | 0.1 | <0.01 | <0.01 | 0.01 | 9. | 0.02 | <0.01 | <0.01 | 2. | 6. |
| Ca | 70. | <16. | <11. | <17. | 0.15 | 0.003 | 0.02 | 0.02 | <4. | 0.03 | 0.003 | 0.01 | 10. | 30. |
| Si | 400. | Major | Major | Major | 0.5 | 0.05 | 0.2 | 0.1 | Major | 0.05 | 0.1 | 0.2 | Major | Major |
| Mg | 10. | <3. | <3. | <10. | 0.05 | 0.002 | 0.01 | 0.01 | <2. | 0.02 | 0.002 | 0.004 | 2. | 6. |
| Co | 0.6 | 0.12 | 0.06 | 0.1 | 0.001 | <0.001 | <0.001 | <0.001 | 0.002 | <0.001 | <0.001 | <0.001 | 0.002 | 0.003 |
| Ti | 2. | <0.007 | <0.007 | <0.007 | 0.003 | <0.001 | <0.001 | <0.001 | <0.002 | <0.001 | <0.001 | <0.001 | 0.007 | 0.02 |
| Zr | 0.08 | <0.12 | <0.06 | 0.17 | <0.001 | <0.001 | <0.001 | <0.001 | <0.015 | <0.001 | <0.001 | <0.001 | 0.02 | 0.03 |
| Ba | 2. | <0.4 | <0.26 | <0.5 | 0.001 | <0.001 | <0.001 | <0.001 | 4. | <0.001 | <0.001 | <0.001 | 0.2 | 0.6 |
| Al | 60. | <10. | <7. | <15. | 0.05 | <0.003 | 0.005 | 0.005 | <2. | 0.003 | 0.005 | 0.005 | 6. | 20. |
| O Soluble | 99. | 161. | 108. | 147. | 114.6 | 2.2 | 8.2 | 12.4 | 23. | 5.5 | 2.6 | 5.7 | 2.2 | 5.6 |
| $Cl^-$ | 6.26 | 17.7 | 5.6 | 15.7 | <0.05 | <0.05 | <0.05 | <0.05 | 2.55 | <0.05 | <0.05 | <0.05 | <0.05 | .05 |
| $SO_4^=$ | 36.0 | 8.2 | 3.5 | 6.3 | 57.8 | <0.2 | <0.2 | <0.2 | 0.8 | <0.2 | <0.2 | <0.2 | <0.2 | .2 |
| $NO_3$ | <0.1 | <0.1 | 0.2 | <0.1 | 0.01 | 0.1 | <0.1 | <0.1 | <0.1 | 0.2 | <0.1 | <0.1 | 0.1 | <0.1 |
| $NH_4$ | <0.03 | <0.03 | <0.03 | 0.03 | 1.47 | 0.07 | 0.07 | <0.03 | <0.03 | 0.03 | <0.03 | <0.03 | <0.03 | <0.03 |
| pH | 6.8 | 6.3 | 6.7 | 6.8 | 2.0 | 4.8 | 4.45 | 6.3 | 6.7 | 5.5 | 5.3 | 6.0 | 7.6 | 8.[illegible] |
| etone Soluble | 12.3 | - - | - - | - - | 0.6 | 400. | 4.8 | 3.0 | - - | 0.8 | 1.2 | 7.0 | - - | - - |

a) OES data from combination of $H_2O$-acetone leach plus residue in beaker.

b) Net value after subtracting appropriate blank.

c) Blank for B-346.

d) Blank for B-339, 340, 341.

Not reported - Se, F, not detected by OES; Bi, Ge, Mo, Sn, Te, and Th, not detected in any samples; detection limits can be supplied if needed.

## VII. CHEMICAL ANALYSIS OF EMISSIONS
## FROM
## A 50% FERROSILICON FURNACE

Chemical analyses were made on particulate samples collected from the outlet gas stream of a venturi scrubber serving a semi-covered furnace producing 50% ferrosilicon. The first tests were made on this scrubber on February 2, 1972, while kerosene was injected into the exhaust system blower, some kerosene was collected in the sample. The samples for these tests are identified as 253 through 257.

The second group of tests were made on July 19, 1972, without kerosene injection into the blower. Combustible material in the sample collected with kerosene injection was about 67 percent and without kerosene injection, about 50 percent.

Sodium, potassium, and calcium analysis appeared to be too high, so a check analysis was made on filter samples 134 and 140 by the atomic absorption method. The results in milligrams were:

| Sample | Sample weight,mg | Na | K | Ca |
|---|---|---|---|---|
| 134 | 98.3 | 83 | 11 | 33 |
| 140 | 103.1 | 81 | 11 | 35 |

This represents the amount of these elements extracted from the collected particulate and the filter material.

# SOURCE SAMPLE REQUEST & REPORT

(MUST BE FILLED OUT FOR EACH TEST RUN)

| SAMPLING DATE | 72 | 2 | 17 |
|---|---|---|---|
| | YR | MO | DAY |

FIRST IDENT. NO. USED 253

LAST IDENT. NO. USED 257

TEST NO.

RUN NO.

INDUSTRY FURNACE H (USE TABLE A)

COMPANY

ADDRESS

SAMPLING METHOD

UNIT PROCESS OPERATION 50% Fe-Si FURNACE

AIR POLLUTION CONTROL SCRUBBER

FUEL USED NONE (KEROSENE INJECTION INTO BLOWER - NO COMBUSTION)

☐ INLET ☒ OUTLET

GAS VOLUME SAMPLED (METER VOL IN FT³) 1.96

| IDENT NO | DESCRIPTION OF SAMPLE OR SAMPLE FRACTION | SAMPLE WT (SOLID) MG | SAMPLE VOL (LIQUID) ML | ANALYSIS REQUESTED - GENERAL COMMENTS (APPROX CONCENTRATIONS - POSSIBLE INTERFERENCES ETC) (INDICATE SPECIFIC ANALYSIS ON BACKSIDE) |
|---|---|---|---|---|
| 253 | ACETONE PROBE WASH RESIDUE | 65.4 | | ORGANICS, COMBUSTIBLES |
| 254 | FILTER (TARE 175.7 mg) | 10.8 | | " " |
| 255 | ACETONE IMPINGER WATER RESIDUE | 18.5 | | " " |
| 256 | IMPINGER WATER RESIDUE | 1.3 | | COMBUSTIBLES |
| 257 | CHLOROFORM - ETHER EXTRACTION RESIDUE | 1.8 | | " |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

COMMENTS:

SAMPLING CONTRACTOR (IF APPLICABLE)

PROJECT OFFICER

REQUEST REVIEWED BY

DATE OF REQUEST

DATE ANALYSIS REQUESTED

DATE OF REQUEST (TO BE FILLED IN BY SSFAB)

EPA(DUR)245

REPORT OF ANALYSIS
TRACE ELEMENTS
ppm - for solid samples
ug/ml - for liquid samples

| Ident No. | Hg | Be | Cd | As | V | Mn | Ni | Sb | Cr | Zn | Cu | Pb | Se | B | F | Li | Ag | Sn | Fe | Sr | Na | K | Ca | Si | Mg | Ba | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Analysis Method: 1-NAA, 2-SSMS, 3-OES, 4-AA, 5-ASV, 6-XRF, and 7-other

Comments:

Other Analysis - Use Table B to fill analysis requested (above each column)

Mark (x) for specific analysis requested

| Ident No. | ORGANICS | COMBUSTIBLES | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 253 | ☐ 10% | ☐ 53% | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 254 | ☐ 30% | ☐ 66% | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 255 | ☐ 29% | ☐ 39% | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 256 | ☐ | ☐ 80% | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 257 | ☐ | ☐ 36% | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Analyst | | | | | | | | | | |
| Method | C-E EXTRACTION | LOW TEMP. BAKING | | | | | | | | |

Comments:

Table E-20. CHEMICAL ANALYSIS OF PARTICULATES FROM FURNACE H

## SOURCE SAMPLE REQUEST & REPORT
(MUST BE FILLED OUT FOR EACH TEST RUN)

SAMPLING DATE 72 7 19 (YR MO DAY)

FIRST IDENT. NO USED 121

LAST IDENT. NO USED 125

TEST NO ______

RUN NO ______

INDUSTRY FURNACE H (USE TABLE A)

COMPANY ______

ADDRESS ______

SAMPLING METHOD EPA-5

UNIT PROCESS OPERATION 50% FeSi FURNACE

AIR POLLUTION CONTROL SCRUBBER

FUEL USED NONE (No KEROSINE INJECTION INTO BLOWER)

☐ INLET ☒ OUTLET

GAS VOLUME SAMPLED (METER VOL IN FT$^3$) 44.01

| IDENT NO | DESCRIPTION OF SAMPLE OR SAMPLE FRACTION | SAMPLE WT (SOLID) MG | SAMPLE VOL (LIQUID) ML | ANALYSIS REQUESTED · GENERAL COMMENTS (APPROX CONCENTRATIONS · POSSIBLE INTERFERENCES ETC) (INDICATE SPECIFIC ANALYSIS ON BACKSIDE) |
|---|---|---|---|---|
| 121 | PROBE WASH RESIDUE | 41.9 | | ORGANICS, COMBUSTIBLES (C, H AND N) |
| 122 | FILTERS (000376, 000378) | 114.4 | | ORGANICS, COMBUSTIBLES (C, H AND N) |
| 123 | IMPINGER WASH RESIDUE | 32.3 | | ORGANICS, COMBUSTIBLES (C, H AND N) |
| 124 | IMPINGER $H_2O$ | 0 | | |
| 125 | CHLOROFORM-ETHER EXTRACT | 1.8 | | COMBUSTIBLES (C, H AND N) |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

COMMENTS: ______

SAMPLING CONTRACTOR ______ (IF APPLICABLE)

PROJECT OFFICER ______

REQUEST REVIEWED BY ______

DATE OF REQUEST ______

DATE ANALYSIS REQUESTED ______

DATE OF REQUEST ______ (TO BE FILLED IN BY SSFAB)

EPA(DUR)245

FURNACE H

TRACE ELEMENTS
or sol ples
ug/ml - for liquid samples

Mark (x) for specific analysis
Mark (x) in block to left of Ident. No. when
quest analys not fu

| Ident No. | Hg | Be | Cd | As | V | Mn | Ni | Sb | Cr | Zn | Cu | Pb | Se | B | F | Li | Ag | Sn | Fe | Sr | Na | K | Ca | Si | Mg | Ba | | | | | Analyst's Initial |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | |
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | |
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | |
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | |
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | |
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | |
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | |
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | |
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | |
| ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | |

Analysis Method: 1-NAA, 2-SSMS, 3-OES, 4-AA, 5-ASV, 6-XRF, and 7-other

Comments:

Other Analysis - Use Table B to fill analysis requested (above each column)

Mark (x) for specific analysis requested

| Ident No. | ORGANICS | COMBUSTIBLES[a] | C | H | N | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ☐ 121 | ☒ 38.3 mg | ☒ | ☒ 35.4 mg | ☐ 3.6 mg | ☐ 0.39 mg | ☐ | ☐ | ☐ | ☐ | ☐ |
| ☐ 122 | ☒ 115.0 mg | ☒ | ☒ 43.3 | ☐ 7.4 | ☐ 1.1 | ☐ | ☐ | ☐ | ☐ | ☐ |
| 123 | ☒ 34.7 mg | ☒ | ☐ 16.6 | ☐ 2.3 | ☐ 0.52 | ☐ | ☐ | ☐ | ☐ | ☐ |
| 124 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 125 | ☐ | ☒ | ☐ 0.89 | ☐ 0.12 | ☐ 0.03 | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Analyst | | | | | | | | | | |
| Method | C-E EXTRACTION | | | | | | | | | |

FURNACE H

Comments: [a] COULD NOT OBTAIN "COMBUSTIBLES". NO BLANKS HAVE BEEN SUBTRACTED FROM THESE RESULTS

Table E-21. CHEMICAL ANALYSIS OF PARTICULATES FROM FURNACE H

# SOURCE SAMPLE REQUEST & REPORT

(MUST BE FILLED OUT FOR EACH TEST RUN)

SAMPLING DATE 72 | 7 | 19 (YR | MO | DAY)

FIRST IDENT. NO. USED 133

LAST IDENT. NO. USED 137

TEST NO ______

RUN NO ______

INDUSTRY FURNACE H (USE TABLE A)

COMPANY ______

ADDRESS ______

SAMPLING METHOD EPA-5

UNIT PROCESS OPERATION 50% FeSi FURNACE

AIR POLLUTION CONTROL SCRUBBER

FUEL USED NONE (NO KEROSENE INJECTION INTO BLOWER)

☐ INLET ☒ OUTLET

GAS VOLUME SAMPLED (METER VOL IN FT3) 45.35

| IDENT NO | DESCRIPTION OF SAMPLE OR SAMPLE FRACTION | SAMPLE WT (SOLID) MG | SAMPLE VOL (LIQUID) ML | ANALYSIS REQUESTED - GENERAL COMMENTS (APPROX CONCENTRATIONS - POSSIBLE INTERFERENCES ETC) (INDICATE SPECIFIC ANALYSIS ON BACKSIDE) |
|---|---|---|---|---|
| 133 | PROBE WASH RESIDUE | 57.1 | | TRACE METALS, $SO_4^=$, $Cl^-$, $NO_3^-$, $NH_4^+$, pH, ORGANICS, WATER INS. |
| 134 | FILTERS (000376, 000378) (TARE 75, 78 mg) | 98.3 | | " |
| 135 | IMPINGER WASH RESIDUE | 43.1 | | " |
| 136 | IMPINGER $H_2O$ | 0 | | — |
| 137 | CHLOROFORM - ETHER EXTRACT | 0.8 | | " |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

COMMENTS: ______

SAMPLING CONTRACTOR ______ (IF APPLICABLE)

PROJECT OFFICER ______

REQUEST REVIEWED BY ______

DATE OF REQUEST ______

DATE ANALYSIS REQUESTED ______

DATE OF REQUEST ______ (TO BE FILLED IN BY SSFAB)

EPA(DUR)245

FURNACE H

REPORT OF ANALYSIS
TRACE ELEMENTS
ppm - for solid samples
ug/ml - for liquid samples

| Ident No. | Hg | Be | Cd | As | V | Mn | Ni | Sb | Cr | Zn | Cu | Pb | Se | B | F | Li | Ag | Sn | Fe | Sr | Na | K | Ca | Si | Mg | Ba | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 133 | | <0.9 | 53 | 53 | <9 | 445 | 90 | 53 | 178 | 3560 | 178 | [illegible] | | 178 | | <250 | 445 | [illegible] | 1425 | 9 | 1750 | 2225 | 625 | 8700 | 890 | 35 | | | | | |
| 134 | | <4 | <40 | <400 | <120 | 200 | <40 | <400 | <120 | 6000 | <40 | 200 | | 26000 | | | <40 | <120 | [illegible] | 3000 | [illegible] | [illegible] | [illegible] | MAJOR | [illegible] | 12000 | | | | | |
| 135 | | <2 | <94 | 235 | <35 | 472 | 142 | <94 | 49 | 235 | 142 | 1180 | | 235 | | <700 | 9 | 172 | 2360 | 9 | 900 | 142 | 1180 | 11800 | 235 | 24 | | | | | |
| 136 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 137 | | <26 | <1000 | <1580 | <460 | 158 | 263 | <1050 | 526 | 1000 | 1000 | 263 | | 263 | | <3000 | 52 | 526 | 2630 | <100 | 2630 | 1000 | 1580 | 52600 | 1000 | [illegible] | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| POSSIBLE FILTER BLANK a | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | <4 | <40 | <400 | <120 | 300 | <40 | <400 | <120 | 3000 | <40 | <200 | | 4000 | | | <40 | <120 | [illegible] | 3000 | [illegible] | [illegible] | [illegible] | MAJOR | [illegible] | 4000 | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Analysis Method: 1-NAA, 2-SSMS, [✓ 3-OES], 4-AA, 5-ASV, 6-XRF, and 7-other

Comments: [2] BLANK VALUES SELECTED FROM PREVIOUS OTHER DATA AND GIVEN TO INDICATE POSSIBLE BLANK LEVELS (FILTER SAMPLE ONLY, [illegible] 134) BLANK NOT SUBTRACTED

Other Analysis - Use Table B to fill analysis requested (above each column) Mark (x) for specific analysis requested

| Ident No. | $SO_4^{=}$ | $CL^-$ | $NO_3^-$ | $NH_4^+$ | pH | ORGANICS | WATER INSOLUBLES [1] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 123 | ☐ <0.5 mg | ☐ 0.41 mg | ☐ 0.30 mg | ☐ <0.02 mg | ☐ 6.3 | ☐ 27.9 mg | ☐ 47.7 mg | ☐ | ☐ | ☐ |
| 134 | ☐ <0.5 | ☐ 0.25 | ☐ <0.2 | ☐ <0.02 | ☐ 8.6 | ☐ 58.[illegible] | ☐ 94.1 | ☐ | ☐ | ☐ |
| 135 | ☐ <0.5 | ☐ <0.05 | ☐ <0.05 | ☐ <0.02 | ☐ 5.7 | ☐ 12.1 | ☐ 15.0 | ☐ | ☐ | ☐ |
| 136 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 137 | ☐ <0.5 | ☐ <0.05 | ☐ <0.05 | ☐ <0.02 | ☐ 5.8 | ☐ 3.3 | ☐ 3.3 | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Analyst | | | | | | | | | | |
| Method | | | | | | | | | | |

Comments: [1] WATER INSOLUBLES INCLUDE ORGANIC MATERIAL. No BLANKS HAVE BEEN SUBTRACTED FROM THESE RESULTS.

Table E-22. CHEMICAL ANALYSIS OF PARTICULATES FROM FURNACE H

## SOURCE SAMPLE REQUEST & REPORT
(MUST BE FILLED OUT FOR EACH TEST RUN)

SAMPLING DATE 73 (YR) 7 (MO) 19 (DAY)

FIRST IDENT. NO. USED 139

LAST IDENT. NO. USED 146

TEST NO

RUN NO

INDUSTRY FURNACE H (USE TABLE A)

COMPANY

ADDRESS

SAMPLING METHOD

UNIT PROCESS OPERATION 50% FeSi FURNACE

AIR POLLUTION CONTROL SCRUBBER

FUEL USED NONE (No KEROSENE INJECTION INTO BLOWER)

☐ INLET ☒ OUTLET

GAS VOLUME SAMPLED (METER VOL IN FT3) 38.26

E-62

| IDENT NO | DESCRIPTION OF SAMPLE OR SAMPLE FRACTION | SAMPLE WT (SOLID) MG | SAMPLE VOL (LIQUID) ML | ANALYSIS REQUESTED - GENERAL COMMENTS (APPROX CONCENTRATIONS - POSSIBLE INTERFERENCES ETC) (INDICATE SPECIFIC ANALYSIS ON BACKSIDE) |
|---|---|---|---|---|
| 139 | PROBE WASH RESIDUE | 34.8 | | TRACE METALS, $SO_4^=$, $Cl^-$, $NO_3^-$, $NH_4^+$, pH, ORGANICS, WATER INSOLUBLES. |
| 140 | FILTERS (000363, 000363) | 103.1 | | " |
| 141 | IMPINGER WASH RESIDUE | 6.9 | | " |
| 142 | IMPINGER $H_2O$ | 0.2 | | " |
| 143 | CHLOROFORM - ETHER EXTRACT | 9.7 | | " |
| 145 | ACETONE BLANK | .037 mg/ml | | NONE |
| 146 | WATER BLANK | .017 mg/ml | | NONE |
| | | | | |
| | | | | |
| | | | | |

COMMENTS:

SAMPLING CONTRACTOR (IF APPLICABLE)

PROJECT OFFICER

REQUEST REVIEWED BY

DATE OF REQUEST

DATE ANALYSIS REQUESTED

DATE OF REQUEST (TO BE FILLED IN BY SSFAB)

EPA(DUR)245

FURNACE H

## REPORT OF ANALYSIS
## TRACE ELEMENTS
ppm - for solid samples
ug/ml - for liquid samples

| Ident No. | | Hg | Be | Cd | As | V | Mn | Ni | Sb | Cr | Zn | Cu | Pb | Se | B | F | Li | Ag | Sn | Fe | Sr | Na | K | Ca | Si | Mg | Ba | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | 139 | | 1 | 80 | 130 | 53 | 935 | 132 | 80 | 132 | 5370 | 400 | 660 | | 400 | | <400 | 133 | 400 | 2650 | 26 | 3650 | 2650 | 1325 | 13230 | 1325 | 53 | | | | | |
| | 140 | | <4 | <40 | <400 | <130 | 400 | 80 | <400 | <120 | 2000 | <40 | 400 | | 36000 | | | <40 | <120 | 4000 | 4000 | 100000 | 80000 | 150000 | [illegible] | 120000 | 34000 | | | | | |
| | 141 | | <6 | <335 | <335 | <55 | 1110 | 335 | <335 | 335 | 335 | 335 | 110 | | 335 | | 1670 | 11 | 110 | 22220 | <22 | 7110 | 335 | 1110 | 22220 | 445 | 55 | | | | | |
| | 142 | | <12 | <490 | 1120 | <122 | 4880 | 730 | <490 | 245 | 2440 | 5370 | 1220 | | 730 | | <3660 | 122 | 245 | 6100 | 245 | 12200 | 4880 | 24400 | 18400 | 2440 | <45 | | | | | |
| | 143 | | <5 | <180 | <275 | <45 | 365 | 90 | <180 | 90 | 365 | 900 | 1365 | | 180 | | <1365 | 18 | 275 | 900 | <18 | 450 | 275 | 450 | 22730 | 450 | <45 | | | | | |
| | | a | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| POSSIBLE FILTER BLANK | | | <4 | <40 | <400 | <120 | 200 | <40 | <400 | <120 | 2000 | <40 | <200 | | 4000 | | | <40 | <120 | 2000 | 2000 | 200000 | 40000 | 20000 | BLANK | 50000 | 4000 | | | | | |

Analysis Method: 1-NAA, 2-SSMS, [✓ 3-OES], 4-AA, 5-ASV, 6-XRF, and 7-other

Comments: a BLANK VALUES SELECTED FROM PREVIOUS OTHER DATA AND GIVEN TO INDICATE POSSIBLE BLANK LEVELS (FILTER SAMPLE ONLY 140) BLANK NOT SUBTRACTED

Other Analysis - Use Table B to fill analysis requested (above each column)

Mark (x) for specific analysis requested

| | Ident No. | ☐ $SO_4^=$ | ☐ $Cl^-$ | ☐ $NO_3^-$ | ☐ $NH_4^+$ | ☐ pH | ☐ ORGANICS | ☐ WATER INSOLUBLES b | ☐ | ☐ |
|---|---|---|---|---|---|---|---|---|---|---|
| X | 139 | <0.5 mg | 0.33 mg | <0.05 mg | <0.03 mg | 6.3 | 19.5 mg | 31.4 mg | | |
| ^ | 140 | <0.5 | 0.37 | <0.2 | <0.08 | 8.5 | 61.6 | 103.5 | | |
| X | 141 | <0.5 | <0.05 | <0.05 | <0.02 | 5.8 | 6.0 | 6.6 | | |
| / | 142 | <0.5 | 0.31 | <0.05 | 0.07 | 6.0 | 3.6 | 5.2 | | |
| X | 143 | <0.5 | 0.13 | <0.05 | 0.04 | 7.9 | 4.6 | 11.2 | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| | | | | | | | | | | |
| Analyst | | | | | | | | | | |
| Method | | | | | | | | | | |

Comments: b. WATER INSOLUBLES INCLUDES ORGANIC MATERIAL. NO BLANKS HAVE BEEN SUBTRACTED FROM THESE RESULTS.

Table E-23. CHEMICAL ANALYSIS OF PARTICULATES FROM FURNACE H.

# VIII. CHEMICAL ANALYSIS OF EMISSIONS FROM A FERROMANGANESE FURNACE

Chemical analyses were made on particulate samples collected from the outlet gas stream of a venturi scrubber serving a sealed furnace producing ferromanganese.

Samples of three of the six test runs were analyzed for trace metals, $SO_4^{=}$, $Cl^-$, $NO_3^-$, $NH_4^+$, pH, organics and water insolubles. Chemical analyses were made of the particulates collected in each section of the sampling train. A total of five separate analyses were made to determine the metals in each portion of the sampling train for one test run.

The samples were water leached for the anion and $NH_4^+$ analysis, and they were acetone leached for the total organic analysis; portions of these leaches were combined with a portion from an additional acid leach-scrubbing step to obtain a sample for optical emission spectrography (OES). A portion of each filter was water and acetone leached for the organics, anions, and $NH_4$+; a separate portion of each filter was acid extracted for the OES sample.

The analysis of the filter and residue samples are shown in Tables E-24 and E-25.

## SOURCE SAMPLE REQUEST & REPORT
(MUST BE FILLED OUT FOR EACH TEST RUN)

SAMPLING DATE 72 | 8 | 16 (YR | MO | DAY)

FIRST IDENT. NO. USED 3147

LAST IDENT. NO. USED 3151

TEST NO

RUN NO

INDUSTRY FURNACE K (USE TABLE A)

COMPANY

ADDRESS

SAMPLING METHOD EPA-5

UNIT PROCESS OPERATION Fe Mn FURNACE (SEALED)

AIR POLLUTION CONTROL VENTURI SCRUBBER

FUEL USED NONE

☐ INLET ☒ OUTLET

GAS VOLUME SAMPLED (METER VOL IN FT$^3$) 167.57

| IDENT NO | DESCRIPTION OF SAMPLE OR SAMPLE FRACTION | SAMPLE WT (SOLID) MG | SAMPLE VOL (LIQUID) ML | ANALYSIS REQUESTED - GENERAL COMMENTS (APPROX CONCENTRATIONS - POSSIBLE INTERFERENCES ETC) (INDICATE SPECIFIC ANALYSIS ON BACKSIDE) |
|---|---|---|---|---|
| 3147 | PROBE ACETONE WASH | 22.7 | | MASS, TRACE METALS, $SO_4^=$, $Cl^-$, $NO_3^-$, $NH_4^+$, pH, ORGANICS, $H_2O$ INSOLUBLES |
| 148 | IMPINGER WATER RESIDUE | 1.5 | | " |
| 149 | CHLOROFORM-ETHER EXTRACTION | 3.0 | | " |
| 150 | IMPINGER ACETONE WASH | 15.3 | | " |
| 151 | FILTER (012399) | 225.6 | | " |
| | | | | |
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COMMENTS:

SAMPLING CONTRACTOR (IF APPLICABLE)

PROJECT OFFICER

REQUEST REVIEWED BY

DATE OF REQUEST

DATE ANALYSIS REQUESTED

DATE OF REQUEST (TO BE FILLED IN BY SSFAB)

EPA(DUR)245

FURNACE K

REPORT OF ANALYSIS
TRACE ELEMENTS
ppm - for solid samples
ug/ml - for liquid samples

| Ident No. | Hg | Be | Cd | As | V | Mn | Ni | Sb | Cr | Zn | Cu | Pb | Se | B | F | Li | Ag | Sn | Fe | Sr | Na | K | Ca | Si | Mg | Ba | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3147 | | <0.3 | 185 | 155 | 19 | 3700 | 370 | <74 | 925 | 7400 | 185 | 740 | | 148 | | <5335 | 110 | 74 | 5550 | 37 | 1850 | 740 | 1300 | 18500 | 550 | 110 | | | | | |
| 148 | | <19 | <796 | 1150 | <192 | 1920 | 193 | <796 | 193 | 1150 | 1540 | 385 | | 3850 | | <5730 | 19 | 193 | 1150 | 77 | 1930 | 15385 | 9615 | 9615 | 1540 | 385 | | | | | |
| 149 | | <19 | <796 | <1150 | <193 | 115 | 193 | <796 | 193 | 1150 | <193 | 385 | | 193 | | <5730 | <19 | <143 | 796 | <77 | 1930 | 796 | 796 | 96150 | 875 | <193 | | | | | |
| 150 | | <3 | <135 | <140 | <30 | 630 | 30 | <135 | 30 | 125 | 30 | 63 | | 63 | | <945 | 30 | 30 | 630 | <13 | 945 | 135 | 315 | 62900 | 950 | <30 | | | | | |
| 151[a] | | <3 | 1773 | <177 | <50 | 13300 | <17 | <177 | <50 | 3865 | <17 | 533 | | <3600 | | — | <17 | <50 | 1330 | <50 | 6650 | 9300 | 73300 | — | 13300 | <130 | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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Analysis Method: 1-NAA, 2-SSMS, [✓ 3-OES], 4-AA, 5-ASV, 6-XRF, and 7-other

Comments: [a] FILTER 3151 CORRECTED FOR BLANK

Other Analysis - Use Table B to fill analysis requested (above each column)

Mark (x) for specific analysis requested

| Ident No. | $SO_4^=$ | $Cl^-$ | $NO_3^-$ | $NH_4^+$ | pH | ORGANICS | WATER INSOLUBLES[b] | | |
|---|---|---|---|---|---|---|---|---|---|
| 3147 | ☐ <0.5 mg | ☐ 0.06 mg | ☐ 0.2 mg | ☐ <0.03 mg | ☐ 6.9 | ☐ 18.2 mg | ☐ 20.6 mg | ☐ | ☐ |
| 148 | ☐ <0.5 | ☐ 0.03 | ☐ 0.6 | ☐ <0.03 | ☐ 6.4 | ☐ <0.5 | ☐ <0.5 | ☐ | ☐ |
| 149 | ☐ <0.5 | ☐ 0.03 | ☐ <0.1 | ☐ <0.03 | ☐ 5.8 | ☐ 1.4 | ☐ 1.8 | ☐ | ☐ |
| 150 | ☐ <0.5 | ☐ 0.03 | ☐ <0.1 | ☐ <0.03 | ☐ 6.5 | ☐ 7.0 | ☐ 9.4 | ☐ | ☐ |
| 151 | ☐ <0.5 | ☐ 0.64 | ☐ <0.1 | ☐ <0.1 | ☐ 7.0 | ☐ 40.8 | ☐ 316.4 | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Analyst | | | | | | | | | |
| Method | | | | | | | | | |

Comments: [b] INCLUDES ORGANICS

Table E-24. CHEMICAL ANALYSIS OF PARTICULATE EMISSIONS FROM FURNACE K

## SOURCE SAMPLE REQUEST & REPORT
(MUST BE FILLED OUT FOR EACH TEST RUN)

SAMPLING DATE 72 | 8 | 17 (YR | MO | DAY)

FIRST IDENT. NO. USED 3157

LAST IDENT. NO. USED 3161

TEST NO ______

RUN NO ______

INDUSTRY FURNACE K (USE TABLE A)

COMPANY ______

ADDRESS ______

SAMPLING METHOD EPA -5

UNIT PROCESS OPERATION FeMn FURNACE (SEALED)

AIR POLLUTION CONTROL VENTURI SCRUBBER

FUEL USED NONE

☐ INLET ☒ OUTLET

GAS VOLUME SAMPLED (METER VOL IN FT³) 188.44

| IDENT NO | DESCRIPTION OF SAMPLE OR SAMPLE FRACTION | SAMPLE WT (SOLID) MG | SAMPLE VOL (LIQUID) ML | ANALYSIS REQUESTED - GENERAL COMMENTS (APPROX CONCENTRATIONS - POSSIBLE INTERFERENCES ETC) (INDICATE SPECIFIC ANALYSIS ON BACKSIDE) |
|---|---|---|---|---|
| 3157 | PROBE WASH | 20.0 | | |
| 3158 | IMPINGER WATER RESIDUE | 1.7 | | ORGANICS, COMBUSTIBLES |
| 3159 | CHLOROFORM-ETHER EXTRACTION | 1.7 | | COMBUSTIBLES |
| 3160 | IMPINGER - ACETONE WASH | 12.5 | | COMBUSTIBLES |
| 3161 | FILTER (012397) | 159.8 | | ORGANICS, COMBUSTIBLES |
| | | | | ORGANICS, COMBUSTIBLES |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

COMMENTS: ______

SAMPLING CONTRACTOR ______ (IF APPLICABLE)

PROJECT OFFICER ______

REQUEST REVIEWED BY ______

DATE OF REQUEST ______

DATE ANALYSIS REQUESTED ______

DATE OF REQUEST ______ (TO BE FILLED IN BY SSFAB)

EPA(DUR)245

FURNACE K

REPORT OF ANALYSIS
TRACE ELEMENTS
ppm - for solid samples
ug/ml - for liquid samples

| Ident No. | Hg | Be | Cd | As | V | Mn | Ni | Sb | Cr | Zn | Cu | Pb | Se | B | F | Li | Ag | Sn | Fe | Sr | Na | K | Ca | Si | Mg | Ba | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Analysis Method: 1-NAA, 2-SSMS, 3-OES, 4-AA, 5-ASV, 6-XRF, and 7-other

Comments:

Other Analysis - Use Table B to fill analysis requested (above each column)

Mark (x) for specific analysis requested

| Ident No. | ORGANICS | C | H | N | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 3157 | ☐ 17.4 mg | ☐ 6.9 mg | ☐ 0.48 mg | ☐ 0.06 mg | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3158 | ☐ | ☐ a | ☐ a | ☐ a | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3159 | ☐ | ☐ 1.0 | ☐ 0.11 | ☐ 0.02 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3160 | ☐ 11.3 | ☐ 5.46 | ☐ 0.73 | ☐ 0.11 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3161 | ☐ 60.8 | ☐ 67.6 | ☐ 4.0 | ☐ 1.0 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Analyst | | | | | | | | | | |
| Method | | | | | | | | | | |

Comments: a Not ENOUGH SAMPLE FOR CHN ANALYSIS. CHN RESULTS ON FILTER SAMPLE (3161) CORRECTED FOR BLANKS

Table E-25. CHEMICAL ANALYSIS OF PARTICULATE EMISSIONS FROM FURNACE K

# IX. CHEMICAL ANALYSIS OF EMISSIONS FROM A SiMn FURNACE

Particulate samples were taken at the outlet of a venturi scrubber serving a silicomanganese furnace (sealed). Samples were collected with an EPA sampling train by EPA method 5 (described in Appendix B of this report). Chemical analyses were made of the collected particulates in each fraction of the sampling train. Metal analyses were made of the two test runs. Analyses of organics, anions, $NH_4^+$, and water insolubles were made of three test runs.

The samples were water leached for the anion and $NH_4^+$ analysis, and they were acetone leached for the total organic analysis; portions of these leaches were combined with a portion from an additional acid leach-scrubbing step to obtain a sample for optical emission spectrography (OES). A portion of each filter was water and acetone leached for the organics, anions and $NH_4^+$; a separate portion of each filter was acid extracted for the OES sample.

The analyses of the filter and residue samples are shown in Tables E-26, E-27, and E-28.

## SOURCE SAMPLE REQUEST & REPORT
(MUST BE FILLED OUT FOR EACH TEST RUN)

SAMPLING DATE 72 | 8 | 17 (YR | MO | DAY)

FIRST IDENT. NO. USED 3162

LAST IDENT. NO. USED 3166

TEST NO. ____

RUN NO. ____

INDUSTRY FURNACE K (USE TABLE A)

COMPANY ____

ADDRESS ____

SAMPLING METHOD EPA-5

UNIT PROCESS OPERATION FeMn FURNACE (SEALED)

AIR POLLUTION CONTROL VENTURI SCRUBBER

FUEL USED NONE

☐ INLET ☒ OUTLET

GAS VOLUME SAMPLED (METER VOL IN FT3) 187.58

| IDENT NO | DESCRIPTION OF SAMPLE OR SAMPLE FRACTION | SAMPLE WT (SOLID) MG | SAMPLE VOL (LIQUID) ML | ANALYSIS REQUESTED - GENERAL COMMENTS (APPROX CONCENTRATIONS - POSSIBLE INTERFERENCES ETC) (INDICATE SPECIFIC ANALYSIS ON BACKSIDE) |
|---|---|---|---|---|
| 3162 | PROBE WASH | 23.4 | 580 | MASS, TRACE METALS, $SO_4^{=}$, $Cl^-$, $NO_3^-$, $NH_4^+$, pH, ORGANICS, $H_2O$ INSOLUBLE |
| 163 | IMPINGER $H_2O$ | 1.8 | 635 | " |
| 164 | CHLOROFORM-ETHER EXTRACTION | 1.1 | 450 | " |
| 165 | IMPINGER ACETONE WASH | 13.1 | 450 | " |
| 166 | FILTER (012393) | 106.0 | — | " |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |

COMMENTS: ____

SAMPLING CONTRACTOR ____ (IF APPLICABLE)

PROJECT OFFICER ____

REQUEST REVIEWED BY ____

DATE OF REQUEST ____

DATE ANALYSIS REQUESTED ____

DATE OF REQUEST ____ (TO BE FILLED IN BY SSFAB)

EPA(DUR)245

FURNACE L

REPORT OF ANALYSIS
TRACE ELEMENTS
ppm - for solid samples
ug/ml - for liquid samples

| Ident No. | Hg | Be | Cd | As | V | Mn | Ni | Sb | Cr | Zn | Cu | Pb | Se | B | F | Li | Ag | Sn | Fe | Sr | Na | K | Ca | Si | Mg | Ba | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3162 | | <2 | 90 | 135 | <23 | 2250 | 135 | <90 | 90 | 450 | 90 | 225 | | 135 | | <675 | 23 | 45 | 1126 | 14 | 1126 | 225 | 1126 | 22520 | 450 | 45 | | | | |
| 163 | | <22 | <900 | 2270 | <227 | 2270 | 900 | <900 | 455 | 900 | 900 | 455 | | 6800 | | <6800 | 45 | 227 | 45150 | 90 | 22730 | 4545 | 11360 | 22730 | 2270 | 900 | | | | |
| 164 | | <35 | <1540 | <2300 | <385 | 770 | <385 | <1540 | <385 | 1540 | <385 | 230 | | 385 | | <11550 | 38 | <385 | 17230 | 154 | 3850 | 3075 | 1540 | 38400 | 1540 | <385 | | | | |
| 165 | | <4 | <155 | 775 | <39 | 1940 | 78 | <155 | 78 | 388 | <39 | 155 | | 233 | | <1162 | 39 | 39 | 1940 | <15 | 1940 | 233 | 1940 | 19350 | 233 | <39 | | | | |
| 166 | | <4 | 1886 | <377 | <113 | 56600 | <37 | <377 | <113 | 15100 | <37 | 1130 | | <5260 | | — | <37 | <113 | 2830 | <113 | 14150 | 17800 | 28300 | | 28300 | <283 | | | | |

Analysis Method: 1-NAA, 2-SSMS, 3-OES, 4-AA, 5-ASV, 6-XRF, and 7-other

Comments: FILTER (3166) CORRECTED FOR BLANK

Other Analysis - Use Table B to fill analysis requested (above each column)

Mark (x) for specific analysis requested

| Ident No. | $SO_4^=$ | $Cl^-$ | $NO_3$ | $NH_4^+$ | pH | ORGANICS | WATER INSOLUBLES * | | |
|---|---|---|---|---|---|---|---|---|---|
| 3163 | ☐ <0.5 mg | ☐ <0.03 mg | ☐ <0.1 mg | ☐ <0.03 mg | ☐ 6.8 | ☐ 14.3 mg | ☐ 16.2 mg | ☐ | ☐ |
| 163 | ☐ <0.5 | ☐ 0.14 | ☐ <0.1 | ☐ <0.03 | ☐ 7.3 | ☐ 2.4 | ☐ 2.5 | ☐ | ☐ |
| 164 | ☐ <0.5 | ☐ <0.03 | ☐ <0.1 | ☐ <0.03 | ☐ 6.0 | ☐ 0.8 | ☐ 0.8 | ☐ | ☐ |
| 165 | ☐ <0.5 | ☐ <0.03 | ☐ <0.1 | ☐ <0.03 | ☐ 6.8 | ☐ 5.6 | ☐ 6.1 | ☐ | ☐ |
| 166 | ☐ <0.5 | ☐ 0.64 | ☐ 0.4 | ☐ <0.1 | ☐ 7.2 | ☐ 5.0 | ☐ 98.4 | ☐ | ☐ |
| Analyst | | | | | | | | | |
| Method | | | | | | | | | |
| Comments: | | | | | | | | | |

* INCLUDES ORGANICS

Table E-26. CHEMICAL ANALYSIS OF PARTICULATE EMISSIONS FROM FURNACE L

## SOURCE SAMPLE REQUEST & REPORT
(MUST BE FILLED OUT FOR EACH TEST RUN)

SAMPLING DATE 72 | 8 | 22 (YR | MO | DAY)

FIRST IDENT. NO. USED 3197

LAST IDENT. NO. USED 3201

TEST NO ____

RUN NO ____

INDUSTRY FURNACE L (USE TABLE A)

COMPANY ____

ADDRESS ____

SAMPLING METHOD EPA-5

UNIT PROCESS OPERATION SiMn FURNACE (SEALED)

AIR POLLUTION CONTROL VENTURI SCRUBBER

FUEL USED NONE

☐ INLET ☒ OUTLET

GAS VOLUME SAMPLED (METER VOL IN FT3) 209.21

| IDENT NO | DESCRIPTION OF SAMPLE OR SAMPLE FRACTION | SAMPLE WT (SOLID) MG | SAMPLE VOL (LIQUID) ML | ANALYSIS REQUESTED - GENERAL COMMENTS (APPROX CONCENTRATIONS - POSSIBLE INTERFERENCES ETC) (INDICATE SPECIFIC ANALYSIS ON BACKSIDE) |
|---|---|---|---|---|
| 3197 | PROBE WASH | 56.1 | 615 | MASS, TRACE METALS, $SO_4^=$, $Cl^-$, $NO_3^-$, $NH_4^+$, ORGANICS, WATER INSOLUBLES |
| 198 | IMPINGER WATER | 0.8 | 770 | " |
| 199 | CHLOROFORM-ETHER EXTRACTION | 1.1 | 450 | " |
| 200 | IMPINGER ACETONE WASH | 12.3 | 390 | " |
| 201 | FILTER (72-618) | 91.3 | – | " |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

COMMENTS: ____

SAMPLING CONTRACTOR ____ (IF APPLICABLE)

PROJECT OFFICER ____

REQUEST REVIEWED BY ____

DATE OF REQUEST ____

DATE ANALYSIS REQUESTED ____

DATE OF REQUEST ____ (TO BE FILLED IN BY SSFAB)

EPA(DUR)245

FURNACE L

REPORT OF ANALYSIS
TRACE ELEMENTS
ppm - for solid samples
ug/ml - for liquid samples

| Ident No. | Hg | Be | Cd | As | V | Mn | Ni | Sb | Cr | Zn | Cu | Pb | Se | B | F | Li | Ag | Sn | Fe | Sr | Na | K | Ca | Si | Mg | Ba | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3197 | | <0.5 | <170 | 3720 | <455 | 5475 | 340 | 34 | 254 | 4240 | 340 | 1700 | | 254 | | <254 | 254 | 34 | 1700 | 85 | 16950 | 16950 | 1700 | 8475 | 1700 | 340 | | | | | |
| 3198 | | <45 | <1820 | 3730 | <455 | 1520 | 910 | 1820 | 910 | 1820 | 910 | <273 | | <5455 | | <13640 | 90 | 1820 | 4550 | <180 | 45450 | 9090 | 22725 | 18200 | 3640 | 455 | | | | | |
| 3199 | | <35 | <1430 | <3410 | <360 | 143 | 360 | <1430 | 360 | 1430 | <360 | <214 | | 360 | | <10715 | <35 | <360 | 3410 | <143 | 3570 | 1430 | 360 | 3143 | 715 | <360 | | | | | |
| 3200 | | <4 | <177 | 1330 | <44 | 1770 | 44 | 177 | 44 | 885 | 44 | 177 | | 88 | | <1330 | <18 | <44 | 265 | 18 | 1770 | 440 | 1330 | 13275 | 350 | 44 | | | | | |
| 3201 | | <4 | <44 | <435 | <131 | 9860 | <44 | <438 | <131 | <438 | <44 | 920 | | <6570 | | | <44 | <131 | <1640 | <131 | 16430 | 23000 | <3285 | — | <3285 | <328 | | | | | |

Analysis Method: 1-NAA, 2-SSMS, [✓ 3-OES], 4-AA, 5-ASV, 6-XRF, and 7-other

Comments: RESULTS ON FILTER SAMPLE (3201) CORRECTED FOR BLANK

Other Analysis - Use Table B to fill analysis requested (above each column)

Mark (x) for specific analysis requested

| Ident No. | $SO_4^=$ | $Cl^=$ | $NO_3^-$ | $NH_4^+$ | pH | ORGANICS | WATER INSOLUBLES | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 3197 | ☐ 0.8 mg | ☐ 1.4 mg | ☐ 0.3 mg | ☐ <0.03 mg | ☐ 7.4 | ☐ 14.4 mg | ☐ 43.8 mg | ☐ | ☐ | ☐ |
| 3198 | ☐ <0.5 | ☐ 0.05 | ☐ 0.1 | ☐ <0.03 | ☐ 7.4 | ☐ 0.5 | ☐ 0.7 | ☐ | ☐ | ☐ |
| 3199 | ☐ <0.5 | ☐ <0.03 | ☐ <0.1 | ☐ <0.03 | ☐ 6.2 | ☐ 0.6 | ☐ 0.7 | ☐ | ☐ | ☐ |
| 3200 | ☐ <0.5 | ☐ 0.04 | ☐ <0.1 | ☐ <0.03 | ☐ 6.6 | ☐ 4.1 | ☐ 4.5 | ☐ | ☐ | ☐ |
| 3301 | ☐ <0.5 | ☐ 0.60 | ☐ <0.1 | ☐ <0.1 | ☐ 9.3 | ☐ 14.3 | ☐ 76.1 | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Analyst | | | | | | | | | | |
| Method | | | | | | | | | | |

Comments: WATER INSOLUBLES INCLUDES ORGANICS

Table E-27. CHEMICAL ANALYSIS OF PARTICULATE EMISSIONS FROM FURNACE L

## SOURCE SAMPLE REQUEST & REPORT
(MUST BE FILLED OUT FOR EACH TEST RUN)

SAMPLING DATE 72 | 8 | 22 (YR | MO | DAY)

FIRST IDENT. NO. USED 3202

LAST IDENT. NO. USED 3206

TEST NO ____

RUN NO ____

INDUSTRY FURNACE L (USE TABLE A)

COMPANY ____

ADDRESS ____

SAMPLING METHOD EPA-5

UNIT PROCESS OPERATION Si Mn FURNACE (SEALED)

AIR POLLUTION CONTROL VENTURI SCRUBBER

FUEL USED NONE

☐ INLET ☒ OUTLET

GAS VOLUME SAMPLED (METER VOL IN FT3) 226.78

| IDENT NO | DESCRIPTION OF SAMPLE OR SAMPLE FRACTION | SAMPLE WT (SOLID) MG | SAMPLE VOL (LIQUID) ML | ANALYSIS REQUESTED · GENERAL COMMENTS (APPROX CONCENTRATIONS · POSSIBLE INTERFERENCES ETC) (INDICATE SPECIFIC ANALYSIS ON BACKSIDE) |
|---|---|---|---|---|
| 3202 | PROBE WASH | 20.8 | 570 | MASS, ORGANICS, COMBUSTIBLES |
| 3203 | IMPINGER $H_2O$ | 2.4 | 765 | " COMBUSTIBLES |
| 3204 | CHLOROFORM - ETHER EXTRACTION | 3.9 | 450 | " " |
| 3205 | IMPINGER ACETONE WASH | 6.7 | 415 | " ORGANICS, COMBUSTIBLES |
| 3206 | FILTER (72-612) | 93.9 | — | " " " |
| | | | | |
| | | | | |
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| | | | | |

E-74

COMMENTS: ____

SAMPLING CONTRACTOR ____ (IF APPLICABLE)

PROJECT OFFICER ____

REQUEST REVIEWED BY ____

DATE OF REQUEST ____

DATE ANALYSIS REQUESTED ____

DATE OF REQUEST ____ (TO BE FILLED IN BY SSFAB)

EPA(DUR)245

FURNACE L

REPORT OF ANALYSIS
TRACE ELEMENTS
ppm - for solid samples
ug/ml - for liquid samples

| Ident No. | Hg | Be | Cd | As | V | Mn | Ni | Sb | Cr | Zn | Cu | Pb | Se | B | F | Li | Ag | Sn | Fe | Sr | Na | K | Ca | Si | Mg | Ba | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
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Analysis Method: 1-NAA, 2-SSMS, 3-OES, 4-AA, 5-ASV, 6-XRF, and 7-other

Comments:

Other Analysis - Use Table B to fill analysis requested (above each column)

Mark (x) for specific analysis requested

| Ident No. | ORGANICS | C | H | N | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 3202 | ☐ 14.6 mg | ☐ 8.38 mg | ☐ 1.02 mg | ☐ 0.13 mg | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3203 | ☐ | ☐ * | ☐ * | ☐ * | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3204 | ☐ | ☐ 3.2 | ☐ 0.33 | ☐ 0.04 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3205 | ☐ 6.7 | ☐ 3.86 | ☐ 0.46 | ☐ 0.09 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3206 | ☐ 46.7 | ☐ 49.5 | ☐ 3.0 | ☐ 0.75 | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Analyst | | | | | | | | | | |
| Method | | | | | | | | | | |

Comments: * NOT ENOUGH SAMPLE AVAILABLE TO OBTAIN CHN ANALYSIS. CHN RESULTS ON FILTER SAMPLE (3206) CORRECTED FOR BLANK

Table E-28. CHEMICAL ANALYSIS OF PARTICULATE EMISSIONS FROM FURNACE L

## APPENDIX F

### Table F-1. UNITED STATES IMPORTS OF REACTIVE METALS AND ALLOYS*

Reproduced from best available copy.

December 1971 Issued: February 1972

| TSUSA NO. | COMMODITY | COUNTRY OF ORIGIN | IMPORTS FOR CONSUMPTION | | | |
|---|---|---|---|---|---|---|
| | | | CURRENT MONTH | | CUMULATIVE, JAN. TO DATE | |
| | | | Short Tons** | Value $1000 | Short Tons** | Value $1000 |
| 607. 3500 | FERROMANGANESE, under 1% Carbon, Commercial | France | 648 | 102 | 2080 | 570 |
| | | Japan | - | - | 262 | 97 |
| | | Rep. S. Africa | 112 | 15 | 224 | 30 |
| | | Sweden | - | - | 124 | 46 |
| | | West Germany | - | - | 1083 | 458 |
| | | TOTAL | 760 | 117 | 3773 | 1201 |
| 607. 3600 | FERROMANGANESE, 1-4% Carbon, Commercial | Canada | - | - | 559 | 118 |
| | | France | 235 | 64 | 1643 | 435 |
| | | Italy | - | - | 652 | 166 |
| | | Japan | - | - | 716 | 177 |
| | | Norway | - | - | 4740 | 1066 |
| | | Rep. S. Africa | - | - | 15392 | 3530 |
| | | Sweden | 851 | 224 | 5344 | 1483 |
| | | West Germany | - | - | 468 | 141 |
| | | Yugoslavia | - | - | 683 | 158 |
| | | TOTAL | 1086 | 288 | 30197 | 7274 |
| 607. 3700 | FERROMANGANESE over 4% Carbon, Commercial | Belgium | - | - | 1456 | 198 |
| | | Canada | - | - | 10 | 1 |
| | | France | - | - | 76474 | 8570 |
| | | India | - | - | 32718 | 3769 |
| | | Japan | - | - | 1777 | 214 |
| | | Norway | 1345 | 169 | 9784 | 1268 |
| | | Rep. S. Africa | 100 | 12 | 86587 | 9900 |
| | | TOTAL | 1445 | 181 | 208806 | 23920 |
| 607. 5700 | FERROSILICON MANGANESE, Commercial | Canada | - | - | 253 | 33 |
| | | France | - | - | 231 | 60 |
| | | Japan | - | - | 342 | 51 |
| | | Mexico | - | - | 2539 | 396 |
| | | Norway | 448 | 65 | 23558 | 2987 |
| | | Sweden | - | - | 659 | 110 |
| | | Yugoslavia | - | - | 2346 | 314 |
| | | TOTAL | 448 | 65 | 29928 | 3951 |

Table F-1. Continued

December 1971

| TSUSA NO. | COMMODITY | COUNTRY OF ORIGIN | IMPORTS FOR CONSUMPTION | | | |
|---|---|---|---|---|---|---|
| | | | CURRENT MONTH | | CUMULATIVE, JAN. TO DATE | |
| | | | Short Tons** | Value $1000 | Short Tons** | Value $1000 |
| 632.3200 | MANGANESE METAL Commercial | Australia | 10 | 27 | 10 | 27 |
| | | Canada | - | - | 24 | 2 |
| | | Cyprus | - | - | 15 | 6 |
| | | Japan | 114 | 45 | 800 | 343 |
| | | Netherlands | - | - | 50 | 23 |
| | | Rep. S. Africa | 82 | 34 | 1979 | 828 |
| | | TOTAL | 206 | 106 | 2878 | 1229 |
| 607.3100 | FERROCHROME, over 3% Carbon, Commercial | Belgium | - | - | 110 | 25 |
| | | Brazil | - | - | 1382 | 291 |
| | | Canada | - | - | 515 | 159 |
| | | Finland | - | - | 10903 | 1138 |
| | | France | - | - | 4256 | 1125 |
| | | Japan | - | - | 12992 | 2923 |
| | | Norway | - | - | 301 | 85 |
| | | Rep. S. Africa | - | - | 7174 | 956 |
| | | Sweden | 220 | 51 | 220 | 51 |
| | | West Germany | 55 | 13 | 11697 | 1620 |
| | | TOTAL | 275 | 64 | 49550 | 8373 |
| 607.3000 | FERROCHROME, under 3% Carbon, Commercial | Canada | - | - | 184 | 43 |
| | | France | - | - | 1086 | 425 |
| | | India | - | - | 2260 | 860 |
| | | Japan | - | - | 7389 | 2942 |
| | | Norway | - | - | 3457 | 1460 |
| | | Rep. S. Africa | - | - | 14632 | 3459 |
| | | Sweden | - | - | 5433 | 2291 |
| | | Turkey | - | - | 1120 | 357 |
| | | West Germany | 142 | 215 | 5033 | 2491 |
| | | TOTAL | 142 | 215 | 40594 | 14465 |
| 632.1800 | CHROME METAL, Commercial | Canada | - | - | 17 | 5 |
| | | France | - | - | 90 | 193 |
| | | Japan | 41 | 87 | 605 | 1147 |
| | | Netherlands | - | - | 2 | 6 |
| | | Un. Kingdom | 35 | 63 | 818 | 1420 |
| | | West Germany | - | - | 102 | 192 |
| | | TOTAL | 76 | 150 | 1634 | 2963 |

## Table F-1. Continued

December 1971

| TSUSA NO. | COMMODITY | COUNTRY OF ORIGIN | IMPORTS FOR CONSUMPTION | | | |
|---|---|---|---|---|---|---|
| | | | CURRENT MONTH | | CUMULATIVE, JAN. TO DATE | |
| | | | Short Tons** | Value $1000 | Short Tons** | Value $1000 |
| 607. 5000 | FERROSILICON, 8-60% Silicon, Commercial | Canada | 74 | 6 | 6038 | 422 |
| | | France | 16 | 7 | 1387 | 492 |
| | | Japan | 50 | 18 | 3587 | 1111 |
| | | Norway | 55 | 17 | 685 | 213 |
| | | W. Germany | - | - | 277 | 75 |
| | | TOTAL | 195 | 48 | 11974 | 2313 |
| 607. 5100 | FERROSILICON, 60-80% Silicon Commercial | Canada | - | - | 791 | 216 |
| | | China | - | - | 28 | 7 |
| | | Denmark | 44 | 17 | 44 | 17 |
| | | France | 69 | 28 | 2837 | 1129 |
| | | Japan | - | - | 50 | 10 |
| | | Norway | 165 | 32 | 2568 | 737 |
| | | Rep. S. Africa | - | - | 319 | 62 |
| | | Sweden | - | - | 3115 | 541 |
| | | W. Germany | - | - | 444 | 161 |
| | | Yugoslavia | - | - | 2224 | 776 |
| | | TOTAL | 278 | 77 | 12420 | 3656 |
| 607. 5200 | FERROSILICON 80-90% Silicon, Commercial | Canada | - | - | 60 | 18 |
| | | Rep. S. Africa | - | - | 14 | 3 |
| | | TOTAL | - | - | 74 | 21 |
| 607. 5300 | FERROSILICON 90% and over, Silicon | | - | - | - | - |
| | | TOTAL | - | - | - | - |
| 632. 1200 | SILICON METAL, Commercial | Canada | - | - | 174 | 74 |
| | | Norway | - | - | 22 | 8 |
| | | Un. Kingdom | - | - | 2 | 2 |
| | | TOTAL | - | - | 198 | 84 |
| 607. 5500 | CHROMIUM SILICON | Sweden | - | - | 772 | 207 |
| | | TOTAL | - | - | 772 | 207 |

Table F-1. Continued

December 1971

| TSUSA NO. | COMMODITY | COUNTRY OF ORIGIN | IMPORTS FOR CONSUMPTION | | | |
|---|---|---|---|---|---|---|
| | | | CURRENT MONTH | | CUMULATIVE, JAN. TO DATE | |
| | | | Short Tons** | Value $1000 | Short Tons** | Value $1000 |
| 607. 7000 | FERROVANADIUM | W. Germany | - | - | 69 | 360 |
| | | TOTAL | - | - | 69 | 360 |
| 607. 6000 | FERROTITANIUM Commercial | France | - | - | 50 | 23 |
| | | Italy | - | - | 20 | 15 |
| | | Un. Kingdom | - | - | 17 | 116 |
| | | TOTAL | - | - | 87 | 154 |
| 607. 6500 | FERROTUNGSTEN | Brazil | 5 | 24 | 6 | 29 |
| | | Sweden | - | - | 12 | 69 |
| | | TOTAL | 5 | 24 | 18 | 98 |
| 629. 2800 | TUNGSTEN, Unwrought | Sweden | 1 | 7 | 7 | 66 |
| | | W. Germany | - | - | 44 | 539 |
| | | TOTAL | 1 | 7 | 51 | 605 |
| 628. 1500 | COLUMBIUM METAL | | (POUNDS & | | DOLLARS) | |
| | | W. Germany | - | - | 450 | 7227 |
| | | TOTAL | - | - | 450 | 7727 |
| 629. 0500 | TANTALUM METAL | | (POUNDS & | | DOLLARS) | |
| | | Canada | - | - | 763 | 3268 |
| | | Japan | - | - | 792 | 10456 |
| | | Mexico | - | - | 22341 | 47739 |
| | | Un. Kingdom | - | - | 16020 | 212355 |
| | | W. Germany | - | - | 175 | 4981 |
| | | TOTAL | - | - | 40091 | 278799 |
| 620. 6000 | ZIRCONIUM METAL | | (POUNDS & | | DOLLARS) | |
| | | Canada | 2047 | 1126 | 4798 | 4546 |
| | | Japan | 44532 | 144284 | 164124 | 549800 |
| | | Netherlands | - | - | 12867 | 11659 |
| | | Sweden | - | - | 7209 | 10805 |
| | | Un. Kingdom | - | - | 240 | 1457 |
| | | W. Germany | - | - | 36692 | 54572 |
| | | TOTAL | 46579 | 145410 | 225930 | 632839 |

Table F-1. Continued

December 1971

| TSUSA NO. | COMMODITY | COUNTRY OF ORIGIN | IMPORTS FOR CONSUMPTION: CURRENT MONTH Short Tons** | IMPORTS FOR CONSUMPTION: CURRENT MONTH Value $1000 | IMPORTS FOR CONSUMPTION: CUMULATIVE, JAN. TO DATE Short Tons** | IMPORTS FOR CONSUMPTION: CUMULATIVE, JAN. TO DATE Value $1000 |
|---|---|---|---|---|---|---|
| 629.1500 | TITANIUM METAL, Commercial | Austria | - | - | 5 | 3 |
| | | Canada | 11 | 5 | 117 | 129 |
| | | Japan | 37 | 69 | 2498 | 4331 |
| | | Netherlands | - | - | 4 | 3 |
| | | Un. Kingdom | - | - | 120 | 130 |
| | | USSR | 437 | 67 | 1335 | 316 |
| | | W. Germany | - | - | 66 | 68 |
| | | TOTAL | 485 | 141 | 4145 | 4980 |
| | Government Purchase | | - | - | | - |
| | | TOTAL | 485 | 141 | 4145 | 4980 |

[illegible] **Gross Weight

# APPENDIX G

## Glossary

| | |
|---|---|
| Blocking Chrome | A high-silicon (10 to 12 percent) grade of high-carbon ferrochromium used as an additive in making chromium steel to block (i.e., stop) the reaction in the ladle. |
| Charging | The process by which raw materials (charge) such as ores, slag, scrap metal reducing agents, and limestone are added to the furnace. |
| Charge chrome | A grade of high-carbon ferrochrome, so called because it forms part of the charge in the making of stainless steel. |
| Chrome ore/lime melt | A melt of chromium ore and lime produced in an open-arc furnace (tilting) and used as an intermediate charge material in the production of low-carbon ferrochrome. |
| Condensed fumes | Minute solid particles generated by the condensation of vapors from solid matter after volatilization from the molten state. |
| Covered furnace | An electric furnace with a water-cooled cover over the top to limit the admission of air to burn the gases from the reduction process. The furnace may have sleeves at the electrodes (fixed seals) with the charge introduced through ports in the furnace cover, or the charge may be introduced through annular spaces surrounding the electrodes (mix seals). |

| | |
|---|---|
| Electrolytic process | A low-voltage direct current causes the simple ions of the metal contained in an electrolyte of modest concentration to plate on the cathodes as free metal atoms. The process is used to produce chromium and manganese metal, which are included with the ferroalloys. |
| Exothermic process | Molten silicon or aluminum or a combination of the two combines with oxygen of the charge, generating considerable heat and creating temperatures of several thousand degrees in the reaction vessel. The process is generally used to produce high-grade alloys with low carbon content. |
| Ferroalloy | An intermediate material used as an additive or charge material in the production of steel and other metals. Historically, these materials were ferrous alloys, hence the name. In modern usage, however, the term has been broadened to cover such materials as silicon, calcium silicon, calcium carbide, etc., which are produced in a manner similar to that used for the true ferroalloys. |

| | |
|---|---|
| Induction furnace | Induction heating is obtained by changing the frequency to electric conductors composing the charge, and may be considered as operating on the transformer principle. Induction furnaces, with low frequency or high frequency, are used to produce small tonnages of specialty alloys through remelting of the required constituents. |
| Open-arc furnace | Heat is generated in an open-arc furnace by the passage of an electric arc either between two electrodes or between one or more electrodes and the charge. The open-arc furnace consists of a furnace chamber and two or more electrodes. The furnace chamber has a lining which can withstand the operating temperatures and which is suitable for the material to be heated. The lining is contained within a steel shell which, in most cases, can be tilted or moved. |
| Open furnace | An electric furnace with the surface of the charge exposed to the atmosphere, whereby the reaction gases are burned by the inrushing air. |
| Pre-baked electrode | An electrode purchased in finished form, available in diameters up to about 152 cm (60 inches). These electrodes come in sections with threaded ends and are added to the electrode columns. |

| | |
|---|---|
| Reducing agent | Carbon-bearing materials such as metallurgical coke, low-volatile coal, and petroleum coke used in the electric furnace to provide the carbon which combine with oxygen from the metallic oxides in the charge to form carbon monoxide. |
| Self-baking electrodes | The electrode consists of a steel casing filled with a paste of carbonaceous materials quite similar to those used to make pre-baked amorphous carbon electrodes. The heat from the passage of current within the electrode and heat from the furnace itself bakes the electrode and volatilizes the asphaltic binders in the paste. |
| Sintering | The formation of larger particles, conglomerates, or masses from small particles by heating alone, or by heating and pressing, so that certain constituents of the particles coalesce, fuse, or otherwise band together. |
| Slag | The more or less completely fused and vitrified matter separated during the reduction of a metal from its ore. |
| Stoking | The means by which the upper portion of the charged materials in the furnace are stirred up. This loosens the charge and allows free upward flow of furnace gases. |

| | |
|---|---|
| Submerged-arc furnace | In ferroalloy reduction furnaces, the electrodes usually extend to a considerable depth into the charge; hence, such furnaces are called "submerged-arc furnaces." This name is used for the furnaces whose loads are almost entirely of the resistance type. |
| Tapping | A process whereby slag or product is removed from the electric submerged-arc furnace. |
| Tapping period | That period of time during which product or slag flows from the electric submerged-arc furnace. |
| Tapping station | The general area where molten product or slag is removed from the electric submerged-arc furnace. |

# ABBREVIATIONS

| | |
|---|---|
| °F | temperature, degrees Fahrenheit |
| acfm | actual cubic feet per minute |
| scf | standard cubic feet measured at 70°F and 29.92 in. Hg. |
| scfm | standard cubic feet per minute at 70°F and 29.92 in. Hg. |
| psig | pounds per square inch guage |
| gr | grain (1 grain equals 64.8 milligrams) - 7000 grains equal 1 pound |
| ppm | parts per million |
| $\mu g/m^3$ | micrograms per cubic meter (0°C and 760 mm Hg) |
| $mg/m^3$ | milligrams per cubic meter (0°C and 760 mm Hg) |
| ton | weight of 2,000 pounds avoirdupois, also, short ton or net ton |
| gross ton | weight of 2,240 pounds avoirdupois |
| kv-a | kilovolt-ampere |
| kw | kilowatt, 1,000 watts |
| Kw-hr | kilowatt hour |
| mw | megawatt, million watts |
| mw-hr | megawatt hour |
| Silvery iron | 15% to 20% ferrosilicon |
| 50% FeSi | 50% ferrosilicon |
| MgFeSi | magnesium ferrosilicon |
| Si | silicon metal |
| CaSi | calcium silicon |
| SMZ | silicon manganese zirconium |
| HC FeMn | high-carbon ferromanganese |

| | |
|---|---|
| MC FeMn | medium-carbon ferromanganese |
| LC FeMn | low-carbon ferromanganese |
| SiMn | silicomanganese |
| FeMnSi | ferromanganese silicon |
| Chg Cr | charge grade ferrochrome |
| HC FeCr | high-carbon ferrochrome |
| LC FeCr | low-carbon ferrochrome |
| FeCrSi | ferrochrome-silicon |
| Cr ore/lime melt | melted chrome ore and lime (CaO) in oxide form |

### Chemical Symbols

| | |
|---|---|
| $Al_2O_3$ | alumium oxide |
| CO | carbon monoxide |
| $CO_2$ | carbon dioxide |
| $CaC_2$ | calcium carbide |
| CaO | calcium oxide (quick lime) |
| $Cr_2O_3$ | chromium oxide |
| Fe | iron |
| $H_2O$ | water |
| MgO | magnesium oxide |
| Mn | manganese |
| P | phosphorus |
| $SO_2$ | sulfur dioxide |

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